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Effects of Wastewater Treatment Facilities on Wetlands in the Midwest

WAPORA, Inc., Chicago, IL

Prepared for

Environmental Protection Agency, Chicago, IL

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Region V
Water Division
230 South Dearborn Street
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Technical Report

The Effects of Wastewater Treatment Facilities on Wetlands in the Midwest

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16. ABSTRACT

The report describes issues of wastewater and wetlands in Midwest States (Minnesota, Wisconsin, Michigan, Illinois, Indiana and Ohio), summaries the existing (includes a bibliography), inventories the 98 existing wetland discharges in EPA Region V and identifies potential sites and topics for additional study. Both natural and constructed ("artifical") wetlands are considered for alternative wastewater treatment technology. Key areas for future study to contribute to a Generic Environmental Impact Statement include: constructed wetlands, hydrologic impacts, long-term ecological effects, legal and administrative constraints, mitigation of impacts, management of receiving wetlands and disease and health considerations.

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Prepared for USEPA Region V

Chicago, Illinois

by

WAPORA, Inc.

Under Contract No. 68-01-5989

September, 1983

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EXECUTIVE SUMMARY

HISTORICAL BACKGROUND

This report presents the results of Phase I of a two phase study on the effects of treated wastewater on wetlands in USEPA Region V. The purpose of the study is to provide background information for use in the preparation of a Generic Environmental Impact Statement on wastewater management alternatives that employ natural or man-made wetlands either as a point of discharge for treated wastewater or as a medium for advanced treatment. The overall goal of the Phase I report is to provide a starting point for obtaining the information needed to analyze the alternatives in the Generic EIS. The objectives of this Phase I study are:

- Identification of the major issues associated with disposal of wastewater in wetlands (major issues have been identified during scoping of the Generic EIS);
- Summarization of the available literature on the effects of treated wastewater on wetlands;
- Inventory wetlands in USEPA Region V that receive treated wastewater;
- Selection of a number of these sites with high potential for further study in Phase II; and
- Identification of major study topics for these sites based on ranking of the relative importance of each of the major issues.

The need for the Phase I study became evident to USEPA Region V because of the number of proposed wetland discharges or wetland treatment alternatives submitted in various facilities plans for Federal 201 grant assistance. Numerous NPDES permit applications requesting a wetland discharge have also been received. Many small rural communities found that routing municipal wastewater discharges to receiving bodies with assimilative capacity was very expensive. Wetland alternative were determined to be economically attractive as discharges sites. This is a particular problem in many parts of Region V where wetlands are locally widespread, and costs of discharge pipe routing are high.

Any introduction of treated wastewater into a wetland must be evaluated carefully during the facilities plan or NPDES permit review because the potential for adverse impacts on this habitat exists in most cases. However, USEPA determined that little information was available concerning impacts of applied wastewater on the wide variety of wetlands types in Region V. The information was required to allow USEPA and similar agencies to make management decisions regarding such discharges. USEPA Region V determined that a Generic EIS should be prepared to address the impacts of these alternatives and to contribute to better decision making. Because of the large data gaps concerning effects of applied wastewater on Region V wetlands, it was not possible to prepare the Generic EIS immediately. The Phase I study was initiated to provide a means of scoping the EIS and filling data gaps so that the alternatives and issues could be fully addressed in the Generic EIS. In Phase II, field data concerning effects of wastewater on selected types of wetlands in Region V will be collected. This information, and the Phase I report, will be used to produce the Generic EIS.

Figure 1 illustrates the specific historical development of the Generic EIS and the relationship of the present study to the Generic EIS. A notice of intent to prepare the EIS was issued on 27 June 1980. A scoping meeting for the EIS was held in October 1980 in Madison WI in which a series of key issues were identified. These have been condensed into issues concerning:

- Use of "constructed" wetlands to treat wastewater;
- Hydrologic impacts;
- Long-term ecological effects;
- Legal and administrative constraints;
- Mitigation of impacts and management of wetlands receiving wastewater; and
- Disease and health considerations.

An extensive literature review was conducted in each major issue area, and in further subdivided categories, to summarize the existing knowledge

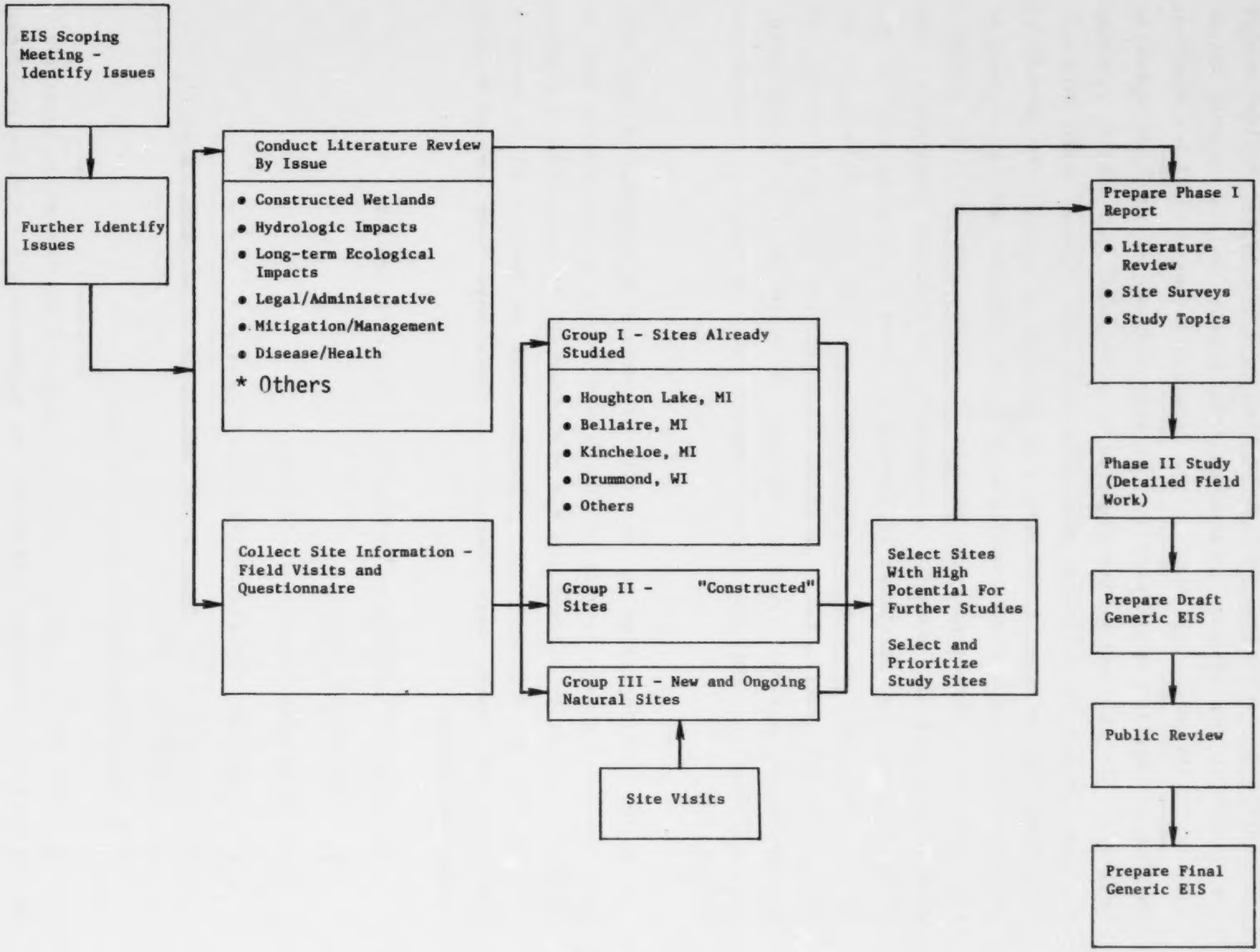
EIS Scoping Meeting - Identify Issues
Further Identify Issues
Conduct Literature Review By Issue
• Constructed Wetlands
• Hydrologic Impacts
• Long-term Ecological Impacts
• Legal/Administrative
• Mitigation/Management
• Disease/Health
* Others
Collect Site Information - Field Visits and Questionnaire
Group I - Sites Already Studied
• Houghton Lake, MI
• Bellaire, MI
• Kincheloe, MI
• Drummond, WI
• Others
Group II - "Constructed" Sites
Group III - New and Ongoing Natural Sites
Site Visits
Select Sites With High Potential For Further Studies
Select and Prioritize Study Sites
Prepare Phase I Report
• Literature Review
• Site Surveys
• Study Topics
Phase II Study (Detailed Field Work)
Prepare Draft Generic EIS
Public Review
Prepare Final Generic EIS

Figure 1. Logic diagram illustrating the relationship of Phase I to Phase II and the Generic EIS.

and to identify data gaps (Figure 1). Simultaneously, a survey was conducted on the nature of existing sites in USEPA Region V sites that currently receive treated wastewater. This involved collecting data on the following three types of sites (Figure 1):

- Group I - sites already studied;
- Group II - sites constructed specifically for advanced wastewater treatment; and
- Group III - sites identified only as wetlands receiving treated wastewater.

A total of five Group I and three Group II sites were identified during the Phase I Study. A total of 161 Group III sites were identified. A questionnaire sent to all Group III site landowners or treatment plant operators resulted in a variety of information on discharge size and duration, types of effluent, and other relevant factors. Site visits were made in 1981 to 38 of the Group III sites to obtain qualitative information concerning wetland type and extent, and other data not obtained via the questionnaire (Figure 1).

The information collected from the site visits, questionnaires, and literature review was analyzed to assign a rating of the potential of each site in Region V for detailed field study in Phase II. Study topics were ranked for Phase II analysis (Figure 1). The study topics chosen were ranked in the same order as those shown in Figure 1.

This Phase I report represents a compilation of the literature review, site inventory survey data, and selection of priority study topics. The following sections summarize the results of the present work in each of these areas.

RESULTS OF LITERATURE REVIEW

ISSUE CATEGORY I: WETLAND STRUCTURE AND FUNCTION - PHYSICAL AND CHEMICAL COMPONENTS

Hydrology

Hydrology is the single most important factor affecting the physical, chemical, and biological components of a wetland. When wastewater is added to a wetland, changes occur in water depth, flooding regime, flow dynamics, and total water budget. These changes in turn alter basic physical and chemical processes such as nutrient cycling, sedimentation rates, erosion patterns, plant and animal species composition, and other central characteristics of wetlands. Critical effects of changing the hydrologic regime of a wetland by applying wastewater may result from:

- Application loading rate;
- Timing of application (seasonal versus continual); and
- Wetland areal extent in relation to loading rate.

A major unknown factor that could affect wastewater treatment is the distribution of internal flow as it relates to residence time and wastewater contact with wetland plants and substrate. Clearly, a high loading rate to a small wetland will result in major hydrologic changes, but a range of situations exist in which wetland size and loading rate vary. Presumably, optimum combinations of size and loading rate exist for most wetland types which would produce minimum hydrologic disturbance and optional treatment effectiveness. However, the literature shows that this combination has not been determined for those wetland types found in Region V. This situation is compounded by the fact that it is very difficult to accurately quantify the hydrologic budget in most wetlands.

Nutrient Cycling and Nutrient Removal

The process of nutrient cycling in wetlands is only very generally understood. Few quantitative studies have been conducted of internal transfer rates of nutrients between ecosystem components. Major nutrient inputs to wetlands include atmospheric precipitation, surface water inflow, and groundwater inflow (ombrotrophic bogs depend primarily on precipitation). Major nutrient outputs typically include surface water and groundwater outflow. Internal cycling processes involve transfer of nutrients between various living and non-living ecosystem compartments. The net sum of these processes results in the observed losses of nutrients to surface water and groundwater outputs.

Two major questions concerning use of wetlands for wastewater include: (1) nutrient removal effectiveness; and (2) the period of time adequate removals rates can be maintain adequate removal rates. In general, wetlands have demonstrated very effective removal of nutrients from treated wastewater. The process, however, is highly variable between different types and ages of wetlands, at different loading rates, and between different soil types. The major pathway for phosphorus removal is via chemical precipitation or physical-chemical adsorption to soil particles. This process is greatly affected by the type of soil; the presence of iron, calcium, or aluminum cations; soil oxygen levels; and availability of adsorption sites (woody plants are also significant permanent nitrogen and phosphorus sinks). When adsorption sites are saturated, further removal of P occurs at a slower rate and is achieved primarily by filtration and in build-up of soil organic matter. The period of time required to reach saturation varies with loading rate, age of the wetland, and size of the wetland.

Another major pathway for nitrogen removal in wetlands is via microbial denitrification at the soil-water interface, including the litter layer. Denitrification is favored by a reduced soil-water interface, and low energy subsidies to the wetland (i.e., low wave or current action favors phosphorus removal). This pathway culminates in the release of nitrogen as atmospheric N.

Two general types of wetlands are present in Region V and these differ in the means by which nutrients are removed. The two general types are northern peatlands and non-tidal freshwater marshes.

The northern peatlands include sphagnum bogs, ombrotrophic bogs, minerotrophic bogs, fens, sedge meadows, cedar swamps, and similar wetland types. The various types of northern peatlands can be further divided into two major categories: bogs and fens. Northern peatlands generally have good removal efficiences for P and N. Removal rates for P vary from 78% to 95%, and for N from 71% to 100%. Phosphorus is initially removed mainly by sorption. Vegetation uptake is not a major removal mechanism. Nitrogen is also removed by microbial denitrification. The long-term potential of using northern peatlands for wastewater application may in fact be limited, and has been questioned.

Non-tidal freshwater marshes include deep and shallow marshes, prairie potholes, reed swamps, and lacustrine marshes. They are distinguished from northern peatlands by their permanently inundated soils. In contrast to northern peatlands, sorption does not seem to be the initial major phosphorus removal mechanism in non-tidal freshwater wetlands. Instead, chemical precipitation and uptake by plants appear to be the primary mechanisms of nutrient uptake. Phosphorus removal rates for freshwater marshes vary roughly between 14% and 82%, whereas nitrogen removal rates range roughly from 38% to 45%.

In summary, the types of processes by which different wetlands remove nutrients, and the general rates of removal, have been identified. Actual nutrient removal performance of specific wetlands types cannot be predicted accurately within the context of the existing data base. Additional long-term studies will be required at priority sites in order to achieve these predictive capabilities.

Accumulation of Other Dissolved Substances

In addition to nutrients, application of wastewater to a wetland may introduce dissolved substances such as organic materials, various inorganic ions such as chloride, magnesium and calcium, and various sulfur compounds. Non-toxic organic materials will produce increased BOD loading. Wetlands have been shown to reduce BOD and COD levels in applied wastewater, but there is a limit to the ability to oxidize these materials. Addition of alkaline water to an acidic wetland will change the plant species composition of the community. A typical change for an acid bog will be towards a cattail monoculture. Little is known about the impacts of other types of dissolved substances on wetland ecology.

Trace Metal Accumulation

Potentially toxic trace metals such as mercury, lead, zinc, cadmium, and copper are usually present in elevated amounts in municipal wastewater. A potential impact on wetlands receiving wastewater could include bioaccumulation of these materials by food chain organisms and subsequent magnification in higher trophic levels. Little is presently known concerning either the details of cycling of trace metals within wetlands, or the ultimate fate of individual trace metal species. Some metals, such as copper, cadmium, and zinc, appear to pass through wetland systems to varying degrees. The percentage of metals retained also varies widely between wetland systems. Important factors in controlling retention of trace metals include soil pH, water column soil oxygen levels, soil composition (organic vs. mineral content), retention time, levels of suspended solids, availability of chelating agents, and types of wetland plants present. Scientific knowledge of these factors must be improved if impacts of trace metals on wetland ecosystems are to be determined.

Accumulation of Refractory Chemicals

Refractory (resistant to decomposition) chemicals such as surfactants, phenols, or pesticides present in wastewater may produce adverse impacts in wetland ecosystems either by exerting direct toxic effects or by bioaccumulating in the food web. Wetlands have been shown to be capable of removing a variety of refractory compounds from wastewater. The long-term ecological effects of these compounds on wetlands receiving wastewater are not known at present.

Changes in Soils and Sediments

The composition of soils varies considerably between wetlands. Many wetlands in the upper Midwest have large accumulations of peat and other organic materials, while river-margin wetlands may have largely mineral soils. The types of soils present in wetlands are primarily a function of the alluvial deposition rate, the biogenic accumulation rate, and the rate of turnover (flushing) of water. Most wetland soils are an intermediate mixture of peats and inorganic sediments. The types of soil present largely determine the effectiveness of the wetland in nutrient removal, as discussed above. Where soils are subsiding, a more permanent phosphorus sink may be made available.

The major potential impacts of applied wastewater on wetland soils include direct erosion and creation of channels under conditions of high loading rates. Chemical leaching of acidic soils by application of basic wastewater may also occur. Erosion impacts can be mitigated by control of flow rates, proper management of channel configuration, and dispersion of the effluent through multiple discharge points. Chemical leaching is at best a poorly understood phenomenon.

ISSUE CATEGORY II: WETLAND STRUCTURE AND FUNCTION - BIOLOGICAL COMPONENTS

Effects on Plant Communities

Five major types of impacts on wetland plant communities can potentially result from wastewater application. These include:

- Long-term changes in species composition;
- Long-term changes in relative areal distribution of component species;
- Changes in biomass, growth, and production;
- Changes in detrital cycling; and
- Transfer of potentially toxic trace metals or other materials into the food chain.

Changes in plant species composition may result primarily from alteration of the hydrologic regime or soil chemical changes (pH or nutrient types and levels). Wetland plants are typically adapted to a specific seasonal flooding cycle or soil moisture levels. Changes in the frequency or duration of flooding, or in average water levels, will therefore alter the species composition of the plant community. Changes in soil pH or nutrient levels or types may also change plant species composition because of individual nutrient requirements and pH regimes. Studies have documented that such changes do occur, especially when an acid bog is treated with wastewater. The trend is to produce a cattail monoculture in this case.

Long-term shifts in wetland plant distribution may result when species dominance is altered due to hydrologic regime or soil chemistry. Species common to an acid bog may be replaced by cattails, which then increase in horizontal extent. Cattail abundance in turn depends on the degree of flooding and extent of soil chemistry alteration. Such changes in species distribution have been well documented.

Increased biomass, growth, and production generally result in some species from elevated nutrients present in the added wastewater. However, in the initial stages of application, the biomass production of the original plant community may decrease as the shift to the new community takes place. These types of changes are only poorly understood over the long-term.

Because wetlands are believed to be detritally driven systems, changes in detrital cycling due to applied wastewater should be thoroughly investigated in future studies. Such changes could result from long-term alteration of primary production rates caused by elevated nutrient levels or by altered soil, water and chemical conditions. As with other ecological impacts, the changes in detrital cycling which actually result will depend on the rate of wastewater loading, timing of discharge, and type of wetland affected. Previous studies have shown that one effect is a build-up of dead plant material in the litter layer. Other studies have shown no difference in decomposition rates between treated and untreated sites. This is probably due to the relatively low seasonal loading rates used. The long-term effects of wastewater application on detrital cycling are not known at this time.

Transfer of Trace Metals into the Food Web

Details concerning retention and bioaccumulation of trace metals by wetland organisms are poorly understood. Only a few studies have been conducted on bioaccumulation of trace metals by wetland organisms. Effects ultimately will depend on the amounts of the metals in the effluent and their availability to organisms. Metals which are retained effectively by certain soil types would have far less potential for adverse impacts since they are not readily available for uptake. Very little quantitative information is available on this subject, and a major data gap exists with respect to long-term impacts. The few short-term studies conducted to date have indicated that bioaccumulation does not occur to any great extent. However, the reasons for this are not clear at present.

Impacts on Wetland Animal Communities

Wetland animal communities include terrestrial wildlife, fish, and invertebrates (including benthic invertebrates and terrestrial insects). Ecological impacts on wetland animal communities may result from shifts in plant community species composition, changes in duration and frequency of flooding, or direct effects due to changes in water quality.

Benthic Invertebrates and Insects

Changes in invertebrate population structure could be caused by reduction of dissolved oxygen levels due to elevated BOD, introduction of elevated amounts of sediments, introduction of toxic compounds, or secondarily, by changes in vegetation composition. These changes could include reductions in abundance and diversity or shifts to more "tolerant" types of benthic organisms. This is a poorly understood subject, however. Direct accumulation of toxic substances in wetland food chains could also occur. Little is known at present concerning the bioaccumulation effects of trace elements in wastewater added to wetlands.

The major issue surrounding flying insect populations is whether increases in disease carrying mosquitoes or similar "vector" species might occur. Very little is known about natural wetland insect populations, and even less is known about insect populations within wetlands receiving wastewater. From a few short-term studies it can be concluded that certain forms such as dipterans (true flies) may increase where wastewater is added to a wetland. Some of these forms could be potential vectors for various encephalitis viruses or similar waterfowl/insect-transmitted diseases. Major information gaps exist concerning disease-related impacts that may occur due to increases in insect vectors.

Impacts on Fish Commmunities

The ecology of fish associated with wetlands is a very poorly understood subject. Wetlands are known to provide permanent habitats, spawning areas, and food for numerous fish species, but few quantitative data are available. Because of high BOD and reduced water quality, a wetland receiving wastewater would probably provide a poor habitat for fish. This has been demonstrated in one study in a Florida cypress dome. Until more is known, impacts on fish will have to be extrapolated from the well developed literature on wastewater impacts on fish in lakes and streams.

Effects on Wildlife

Wetlands provide a highly valuable wildlife habitat. They provide food, shelter, and areas for breeding, nesting and other activities required by many different wildlife species. Changes in the wildlife community at a wetland receiving effluent may result from alterations in water level, structure and composition of the vegetation, interspersion of vegetation and water, and availability of submerged plants, aquatic and terrestrial insects, and other sources of food. Changes in the number and abundance of adults and young of prey species such as amphibians, small birds, and small mammals may result in changes in the composition of carnivorous species of birds and mammals in higher trophic levels.

Changes in water levels due to wastewater discharge could result in shifts of the locations of wildlife breeding foraging and nesting activity within and between wetlands and adjacent upland areas. Water-level changes also influence the types and amounts of food organisms present. Wastewater entering the wetland may contain pathogenic organisms and trace metals that can be taken up directly by individual wildlife or indirectly through the organisms on which they feed.

The few studies published to date have shown that certain types of changes occur in wetland wildlife communities that receive wastewater. In Florida cypress domes, significant increases in bird diversity were observed in the treated dome. In addition, the species of aquatic mammals observed in the treated dome were different from those in a control dome. Amphibians increased in the treated dome because animals were attracted by the higher water levels for breeding. Poor water quality prevented breeding, however. The treated dome was also an amphibian refuge during dry weather. At Houghton Lake, Michigan, long-term data have shown that muskrat populations increased significantly over a six year period due to the increased abundance of cattails. A small increase in meadow voles also resulted near the discharge, because of an increased abundance of grasses. No major shifts in abundance or species composition of bird populations occurred at Houghton Lake.

Wildlife habitat was substantially improved in volunteer wetlands at the Vermontville, Michigan, site. Various authors have also reported improvement in mammal, bird, reptile, and amphibian habitat quality at various other natural and constructed wetland sites. However, the long-term effects on wildlife are still not known.

Rare, Threatened, or Endangered Species

Because wetlands provide excellent habitat for numerous species of rare, threatened, or endangered plants and animals, there is a potential for adverse impacts to occur as a result of wastewater additions. Because of the laws protecting such species, potential treatment sites must be thoroughly examined to determine whether protected species are present. The presence of one or more protected species could reasonably preclude any use of the site for purposes of wastewater disposal.

ISSUE CATEGORY III: POTENTIAL FOR ENHANCEMENT OF WILDLIFE

The availability of a continuous source of water and nutrients associated with a wetland discharge has been suggested as a potential resource for the creation, maintenance, and enhancement of wetland habitats. On the basis of preliminary results obtained at a few sites, it appears that the introduction of wastewater to natural wetlands is followed by a decrease in the diversity of wildlife species and the decline or disappearance of sensitive species intolerant to changes in physical and chemical parameters. This is coupled with an increase in the number and abundance of opportunistic and common species that can adjust to a wider range of habitats. A number of researchers who have conducted ecological investigations at wastewater discharge sites have recommended that wastewater not be discharged to natural wetlands. They indicated that wastewater should be discharged on a carefully controlled experimental basis, or that only discharges to degraded wetlands be allowed, until more information is obtained. The potential for using treated wastewater to enhance pre-existing wetlands may be low because of the likelihood of adverse effects on the wildlife and fish communities. The actual use of wastewater to enhance wetlands may thus be limited to use in previously degraded systems. However, the creation of new wetlands, although of possibly lower quality, would likely have positive returns.

ISSUE CATEGORY IV: HEALTH/DISEASE CONSIDERATIONS

The primary health and disease related considerations in wetlands receiving applied wastewater involves potential human and animal health impacts which may arise from viruses, bacteria and parasites. A variety of pathogenic and non-pathogenic types of these organisms may be present in treated wastewater. Current scientific knowledge concerning the abundance, distribution, and reproductive cycles of disease organisms in natural wetlands, however, is extremely limited. Even less is known concerning the fate of disease organisms in wetlands receiving treated wastewater.

Possible human disease organisms that may be associated with the application of wastewater to wetlands include the protozoan parasite Giar dia lamblia. No information is available concerning its survival in wetlands. Viruses such as adenoviruses and enteroviruses are susceptible to chlorination although some usually survive treatment. However, certain waterborne viruses that cause gastroenteritis and types A & B hepatitis may be associated with wetland-wastewater treatment systems. No studies of these concerns have yet been conducted in wetlands, partly because of the many technical difficulties involved.

In a study of Florida cypress domes receiving chlorinated effluent, 99% of the polio viruses present in the effluent were effectively removed and held in place by the sandy clay loam soil underlying the dome. At Houghton Lake, Michigan, reovirus and polio virus were detected in all samples collected from the wetland and from the treatment plant. The wetland was determined to be a hostile environment for the polio virus but not the reovirus.

Most bacteria are highly susceptible to chlorination. Although a wide variety of pathogenic bacteria have been identified in treated municipal wastewater (most notably Salmonella) few studies have been conducted on pathogenic forms at wetland treatment sites. Studies of non-pathogenic fecal coliform bacteria at several treatment sites have shown that their removal is dependent on wastewater retention time, degree and type of contact between the soil and wastewater, and flow rate. Removal efficiency is lower in deeper water situations. Background levels of fecal coliforms have been reported to be high but variable in freshwater wetlands. A type of enteric bacterium other than Salmonella has therefore been recommended for study of removal rates and removal effectiveness of pathogenic bacteria.

The primary dangers to wildlife health include:

- Introduction of pathogenic organisms from dairies, poultry or livestock farms or similar facilities;
- Possible outbreaks of botulism;
- Introduction of contagious human pathogens or parasites that could be transmitted to wildlife. Direct toxic effects of trace metals, chlorine or other dissolved materials might occur, but such effects are unlikely because of the small quantities of these substances introduced.

Although a variety of diseases are potentially associated with wetlands, the greatest risk for disease is posed to waterfowl and shorebirds. Little scientific information is currently available concerning disease transmission to various forms of wildlife at wetland treatment sites. These populations are also exposed at treatment ponds.

Viruses such as equine encephalitis may be transmitted to wildlife by mosquitoes. Infected birds may in turn transmit this disease to other areas during migration. A potential also exists for transmitting viruses from wetlands receiving poultry, feedlot or other animal wastes directly to wildlife. Polio and turberculosis viruses used to inoculate poultry may survive sewage treatment and enter a wetland.

Bacterial diseases that could affect wetland wildlife include Aeromonas which affects birds, fish, and reptiles; and Salmonella which affects turtles. Muskrats may contract hemorrhagic diseases. A potential also exists for the transmission of avian botulism at wetland treatment sites. Botulism is a bacterial disease which requires anaerobic conditions to develop. Six forms of Clostridium botulinum, the disease causing organism, exist which could potentially affect wildlife. Transmission occurs as a result of ingestion of contaminated invertebrates, especially fly larvae developing on animal carcasses. Isolated botulism outbreaks have occurred at standard sewage treatment facilities in the past, but virtually nothing is known about the scientific aspects of the disease in wetland treatment sites.

ISSUE CATEGORY V: OVERLOADING AND STRESS CONDITIONS

Addition of wastewater to a wetland may overload the system, producing ecological stress. Stress on a wetland receiving wastewater may lessen the system's productivity by diverting energy into different metabolic pathways (i.e., respiration increases, rates of photosynthesis decrease), interfering with normal energy flow patterns. This may produce a variety of little known but potentially significant ecological effects. In general, stress increases with additional loading. Presumably, at some rate of discharge relative to wetland size or type, the wetland will not be able to assimilate all of the waste being added, and normal functions will be adversely affected. No studies have been done to determine at what point this occurs for various wetland types, or what the abilities of natural wetlands are to resist stress caused by applied wastewater.

ISSUE CATEGORY VI: DESIGN, OPERATION AND MONITORING CONSIDERATION

The design engineering of wetland treatment systems is still in its early phases of development, although much has been learned at sites such as Houghton Lake, Michigan. Important factors in designing a wetland treatment system include:

- Water depth and flow;
- Residence time;
- Nutrient loading rates;
- Cover type;
- Soil type;
- Discharge schedule; and
- Age of system.

General design principles have emerged for some of the above areas. Optimal plant cover type, soil type, and discharge scheduling are still not well defined. Wetland performance is generally correlated with overall system features, but treatment effectiveness is not fully predictable since information is lacking in several key areas. Additional research is needed to fill these data gaps. (Practical considerations to take into account when planning a system are listed in Appendix B.)

The operation and maintenance requirements for wetland treatment systems are also in a relatively early state of development. Options for operation include mode of discharge (direct versus multiple), rate of discharge, configuration of receiving wetland (channeled versus sheet flow), and timing of the discharge (seasonal versus year round). Maintenance requirements have received little study and are poorly known. The term maintenance implies application of a corrective action to compensate for an adverse effect within the wetland. Two alternatives, either a total "hands off" attitude or an avoidance of deep water situations, have been employed to date.

No standardized monitoring requirements have yet been developed by regulatory agencies for wetland treatment systems. The task is difficult because a wetland ecosystem does not fit the traditional pattern of a sewage treatment plant and a receiving water body. At least two points of view have arisen. These are:

- That the wetland is a receiving water body, and therefore, influent should be controlled; and
- The wetland is a part of the treatment plant, and therefore, the outfall from the wetland should be controlled.

Guidelines need to be established that set water quality parameters for discharges from a wetland ecosystem connected to a wastewater treatment plant. Difficulties can arise because natural wetlands may violate certain accepted water quality standards, such as limitations on suspended solids.

ISSUE CATEGORY VII: CONSTRUCTED WETLANDS

Constructing new wetland areas for wastewater treatment has gained considerable support as an alternative to the possible degradation of existing wetlands or for use as a means of advanced treatment. Constructed wetlands have demonstrated the ability to treat applied effluent to secondary standards at almost all times, and to advanced treatment standards on a seasonal basis. With appropriate design considerations, these systems can be constructed with low energy requirements (little pumping required) and minimal operation and maintenance demands. This is accomplished while simultaneously increasing wildlife habitat and vegetation production.

Since the 1950's, data on this type of system have been developed on different combinations of wetland size, configuration, depth, flow, vegetation type, and substrate type. The types of systems examined included:

- Large open marsh basins operating in a mode similar to overland flow;

- Narrow marsh trenches with coarsly textured substrate using subsurface flow and underdrains; and

- Intermediary marsh channels with surface overflow.

However, considerably more data are needed on municipal scale facilities (0.25 - 0.5 mgd) with several years of record to adequately assess the long term reliability of this treatment method. No facilities currently exist in the six states of USEPA Region V that could provide those data based upon local conditions.

Design considerations are primarily limited by the availability of sufficient land within a reasonable transmission distance from the wastewater generation source. Constructed wetlands are a land intensive system (50 acres per mgd) and, therefore, land costs or availability may limit implementation of such an alternative. Constructed wetlands may be placed on almost any land area with minimal slope and nominal depth to bedrock. They may be designed independent of the transmissivity or adsorption capacity of surficial soils.

Design criteria have varied according to the types of effluent applied. These have ranged from raw primary effluent to effluent from an activated sludge wastewater treatment plant. A highly effective system has been designed at Listowel, Ontario, based upon lagoon effluent at an application rate of 200 m^3/ha/day (20,000 gal/acre/day), with a seven day retention time and a water depth of 10 cm in summer and 30 cm in winter. The Listowel experiments demonstrated that with these design characteristics, a marsh trench configuration with a length to width ratio of 20:1 consistently out-performed an open marsh.

Operational considerations include application flow control and water quality monitoring. The benefits of this type of system over a natural wetland are that operational controls may be designed to regulate flow, application rates, and detention time for seasonal variations and treatment needs. Flow control is necessary to maintain aerobic conditions within the wetland in order to achieve maximum treatment efficiency and limit potential odor and disease problems.

The primary function of a constructed wetland treatment system is for nutrient removal. The efficiency of a wetland in treating nitrogen to advanced secondary standards is generally good. Phosphorus removal rates, however, have varied. The initial phosphorus treatment efficiency of a constructed wetland is dependent upon the availability of absorption sites in the soil, and such sites are eventually saturated over longer periods of time. Investigators have used substrate materials ranging in texture from coarse gravel to heavy clay. However, little data has been generated to show the relative merits or treatment efficiencies of using a given soil material. Experiments should be conducted to test treatment variations between sand; a sandy loam; a mineral soil high in iron, calcium, and magnesium; organic soil; and clay.

The function, structure, and composition of vegetation in constructed wetlands is generally well documented. Emergent hydrophytic plants become established easily, and have demonstrated luxuriant growth in this environment. However, data are needed on a system that employs woody stem species, which represent a more permanant nutrient sink. Woody plants are reported as being able to store higher concentrations of phosphorus in their trunks and stems than do emergent species which also die back annually.

ISSUE CATEGORY VIII: MITIGATION

Mitigation includes measures to prevent, reduce, or avoid potentially adverse impacts on the environment. In the case of wetland application of wastewater, a variety of mitigative measures are available. Early project planning within the 201 facilities planning process is probably the most effective means of mitigating adverse effects of a wastewater discharge. For wetland treatment systems, migitation may include measures to achieve for required standards. Mitigation consists primarily of determining optimal discharge flows (to avoid overloading and poor treatment), retention times, and timing of discharge (seasonal versus year-round). For a wetland discharge system (no treatment intended), mitigation might consist of water level control, installation of filter structures, control of flow patterns, or consideration of multiple-use opportunities (e.g., use of the wetland for recreation). Such measures would reduce the effects of erosion, improve the treatment of the effluent, or enhance wildlife habitat quality. However, since little is known about the long-term impacts of wastewater on wetlands, specific physical mitigation measures need to be developed. Many of the potential problems and issues associated with wetland discharges and wetland treatment systems may ultimately be resolved by exploring various effective mitigative measures.

ISSUE CATEGORY IX: LEGAL, REGULATORY, AND ADMINISTRATIVE CONSIDERATIONS

A number of legal, regulatory, and administrative issues surround the use of wetlands for disposal or treatment of municipal wastewater. These issues result from requirements of the Federal Clean Water Act, the Executive Orders for protection of floodplains and wetlands, and certain state-specific precedents.

Applicable sections of the Federal Clean Water Act include Section 201 (facilities planning), Section 303 (water quality standards), Section 402 (National Pollutant Discharge Elimination System), and Section 404 (dredge and fill programs).

The 201 facilities planning process currently does not include a specific means whereby a wetland treatment system or discharge can be evaluated and reviewed during the planning process. However, the US Fish and Wildlife Service has developed a method for incorporating such projects into the 201 process at an early phase. This method involves procedural steps by which the existing wetland and the potential impacts of the proposed alternatives are examined. This information is used to determine whether the project is consistent with applicable laws and regulations regarding wetland degradation. Use of such a means of conflict resolution would be helpful in achieving proper planning and management at wetland discharges sites.

A major problem of wetland discharges under the Clean Water Act is that permit conditions must be specified for the receiving waters. Due to problems in assessing wetland boundaries, this may be difficult to determine. In the long term, decisions must be made regarding how wetland discharges will be regulated and monitored.

Executive Order 11990, Protection of Wetlands, requires that Federal agencies minimize degradation of the natural values of wetlands. The order has been variously interpreted with regard to the term "degradation." Since researchers have demonstrated that wastewater application enhances certain aspects of wetland values while reducing ofers such as species diversity, it remains to be determined what precisely constitutes "degradation."

Executive Order 11988, Floodplain Management, directs federal agencies to minimize the impacts of floods on human health and to preserve the beneficial value of floodplains. It has not yet been determined whether Federal agencies would be directly supporting floodplain development in the case of a wetland treatment system or discharge. A major problem which has yet to be resolved concerns the flood-proofing of wetland wastewater treatment systems, and the possible effects of flood damage on such systems.

State and local regulations may also preclude the use of wetlands for purposes of wastewater disposal or treatment. These restrictions may arise through legislation dealing with water quality, floodplain development or wetlands protection. Legislation specific to wetlands and wastewater has only been developed by the States of Michigan and Florida. What is needed is a reassessment of policy interpretations and regulatory issues at all governmental levels to recognize the concept of multiple uses of wetland areas, including wastewater discharges.

INVENTORY OF WASTEWATER DISCHARGES TO WETLANDS IN REGION V

A major part of the present study was to conduct an inventory of existing wetland sites in Region V which were determined to be receiving treated wastewater. Telephone contacts were initially made with various state agencies to request lists of possible sites. Except for Wisconsin, no states had made such a list. Additional information was gathered from NPDES permit files in each state to determine whether the receiving waters were classified as wetlands. Visits were made to each state pollution control agency to collect detailed information on sites that appeared to involve wetland discharges. A questionnaire requesting information on the type and extent of the wetland, the nature and duration of the discharge, and other data, was also sent to selected facilities.

A total of 161 facilities were initially identified as potentially having discharges to wetlands. A total of 38 sites, representing a cross section of wetland types, discharge types (industrial versus municipal), location (state), length of time of discharge, volume of discharge, wildlife values, and other features were selected for a qualitative field survey performed between November 1980 and January 1981. The purpose of the site visit was to determine the actual nature of individual representative wetlands and the overall environmental setting in which they occurred. This included determination of the surrounding land use, areal extent of the wetland, type of wetland, condition of vegetation in the vicinity of the discharge, and estimated wildlife value of the wetland. The relative accessibility of each wetland area for future researchers was also determined.

For natural wetlands, 98 of the 161 facilities inventoried were shown to actually have discharges to a wetland. These included a variety of wetland types such as tamarack bogs, cattail marshes, bottomland forests, and reed-canary grass marshes. Other facilities were eliminated for various reasons (discharge had ended, was routed to another water body, etc.). About 6% of the 98 "natural" sites were municipal wastewater facilities, 17% were commercial facilities, and 6% were from a variety of other discharge types.

A total of 26 of the natural sites were identified as having a high potential for further studies in Phase II. A sites potential for further study was based on the same criteria as used in the initial screening, in order to obtain a selection of wetland types, loading rates, discharge types, discharge durations and geographic representation. A total of three "natural" sites (Bellaire, Michigan; Drummond, Wisconsin; and Houghton Lake, Michigan) were identified as existing wetlands currently being used specifically for purposes of advanced treatment of municipal wastewater.

Three additional natural sites were determined to be candidates for use as advanced treatment facilities (Biwabik, Minnesota; Keilkenny, Minnesota; and Laona, Wisconsin). No full scale "constructed" wetlands were located within Region V. Three sites characterized as "volunteer" wetlands which have developed in response to seepage or similar conditions, were identified (Lake Odessa, Wisconsin; Paw Paw, Michigan; and Vermontville, Michigan). However, a far greater number of volunteer wetlands definitely exists in Region V, based on the results of the field survey, in which several sites were characterized by wetland plants growing in the vicinities of discharges, seepage from stabilization ponds, or within the stabilization ponds themselves.

ISSUE PRIORITIES AND STUDY TOPICS SELECTION

Since all issue categories could not be studied at all of the 26 sites identified as having high potential for further sampling, major issues were categorized and ranked in importance so that priorities for funding could be established. In addition, study topics were identified for each major issue area. In Phase II, these topics will be developed in detail for application at a smaller number of specific selected sites in Region V.

Major issue priorities were established through extensive internal review within the USEPA, and included consideration of all of the review comments on the draft Phase I report from the projects Technical Advisory Committee. A total of six major issue categories were selected. These included: (1) use of constructed wetlands; (2) impacts on the hydrologic regime; (3) long-term ecological effects; (4) legal/administrative issues; (5) mitigation/management issues; and (6) disease/health considerations. Major study topics were also selected and assigned to each of these issue categories, to be further developed in Phase II.

FUTURE STUDIES

This final technical report culminates the Phase I efforts in the overall process of preparing a Generic Environmental Impact Statement on the Effects of Wastewater Treatment Facilities on Wetlands in the Midwest. It has presented the results of a comprehensive literature review, a summary of all known wetland discharge sites, and a ranking of the priority study topics to be evaluated at potential study sites. Phase II will encompass the necessary steps to develop the information for completion of a Draft and Final EIS. These steps will include completion of a 2-year effort in gathering field data, publication of an annotated bibliography in cooperation with the U.S. Fish and Wildlife Service, and development of a legal/administration regulatory document. When these steps have been completed, the scope of the Generic EIS will be defined in more depth based on the data compiled and the Draft and Final EIS documents will be prepared.

Project #0855 March 31, 1983

FINAL TECHNICAL REPORT

THE EFFECTS OF WASTEWATER TREATMENT FACILITIES ON WETLANDS IN THE MIDWEST

CONTRACT NO. 68-01-5989

DOW #5

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1.0. INTRODUCTION

1.1 Rationale for the Present Study

During the past several years, the Water Division of USEPA Region V has reviewed numerous facility plans, environmental reports, and NPDES permit applications involving the discharge of secondarily treated wastewater to natural wetlands. The majority of these applications propose to use wetlands as discharge points for the wastewater. A small number also involve using the wetlands specifically for advanced treatment (i.e., as a final polishing step in the treatment process).

In many rural communities with limited funds for construction and operation of sewage treatment facilities, discharging wastewater to a wetland may, in the course of planning, appear to be a cost-effective alternative. However, all such proposals must be considered by USEPA in the light of its mandate to: ". . . take action to minimize the destruction, loss, or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands. . ." as stated in Section (1) of Executive Order 11990. State, local, and county governments may also be required to protect wetlands under a variety of additional laws and regulations.

Deciding when a particular proposal is in conflict with these goals has been extremely difficult in the past, since essential information needed to make such decisions objectively has not been available. Studies of the impacts of wastewater discharges on the wide variety of wetland types in Region V have not been performed in sufficient depth, nor are reliable data available on the abilities of the numerous different types of wetlands to treat wastewater. Consequently, it has not been possible to establish clear guidelines for permitting discharges into wetlands. The situation has been further complicated by the lack of a precise and consistent definition of the term "wetland" among agencies and permit applicants.

USEPA Region V determined that the acquisition and dissemination of the information necessary to resolve these questions would enable the present standards utilized in the permitting process to be replaced with a less subjective basis for allowing proposed discharges to wetlands and/or the use of wetlands specifically for tertiary treatment. USEPA therefore initiated the present study as part of a generic Environmental Impact Statement (EIS) under Region V's 201 Facilities Plan Program.

The scoping and public participation process for the generic EIS resulted in the identification of major issues that needed to be addressed concerning the application of wastewater to wetlands. These issues formed the structural basis of the present investigation. These issues are as follows:

- Issues concerning potential impacts of wastewater on wetland hydrology,
- Issues concerning impacts on water chemistry, sediment chemistry and nutrient recycling processes;
- Issues concerning impacts on wetland energy flow and plant and animal abundance, diversity, distribution, and production;
- Issues concerning potential effects of disease organisms in wastewater (viruses, bacteria, protozoans) on human, wildlife, and plant health;
- Issues concerning potential impacts of increased ecological stress and overloading caused by elevated levels of nutrients, trace metals, chlorine, and other pollutants introduced into wetlands by wastewater;
- Issues relating to alternative means of designing, operating, and monitoring wetlands which are used specifically as a means of tertiary treatment of wastewater;
- Issues concerning use of constructed and volunteer wetlands for wastewater treatment, including year-round treatment effectiveness, design and operation considerations, and past performance of previously studied systems;
- Issues relating to the effective mitigation of ecological impacts on wetlands which are used either as a point of discharge for wastewater or as a means of tertiary treatment; and
- Legal and regulatory issues concerning the discharge of wastewater to receiving wetlands or use of wetlands for tertiary treatment, including possible conflicts with Executive Orders on wetlands and floodplains, the Clean Water Act, and state and local laws and regulations.

During the initial stages of developing the generic EIS, it became evident that there were major data deficiencies in the scientific literature concerning long-term impacts of wastewater application to wetlands. These data gaps made it impossible to: (1) develop a sound basis for addressing the above issues in a generic EIS; and (2) to arrive at suitable guidelines either for communities desiring to apply for wetland discharges or for applicants interested in the use of natural or constructed wetlands for advanced treatment. As a result, it was determined that detailed studies should first be conducted at selected representative wetlands in Region V to obtain the needed data. The present report is Phase I of a two-phase project in which the needed scientific information will be obtained. The results of these studies will be used to prepare the Draft Generic EIS. Ultimately, this will allow for improved decision making relative to permitting discharges or treatment sites involving wetlands. This approach to taken since it will result in a significant savings in time and funds by eventually eliminating the need for extensive studies to be conducted at individual sites.

The overall objectives of the Phase I portion of the study are: (1) to define the major issues that need to be resolved concerning discharge of secondarily treated wastewater to wetlands; (2) to review the available scientific literature in each major issue category, and to identify data deficiencies; (3) to provide a review of the scientific methodologies available to study the impacts of wastewater application on fresh water wetlands in Region V (4) to provide an inventory of the wetlands in Region V that are currently being used as discharge points for secondarily treated wastewater, or that are being used specifically for advanced treatment (including constructed wetlands); (5) to identify existing sites in Region V that would have a high potential for study in Phase II of the project; and (6) to identify issues of concern and research topics for study in Phase II. The present study does not detail discussion on salt or brackish-water wetlands, aquaculture systems, effects of sludge disposal or effects of non-point source runoff.

In Phase II, detailed site specific studies are to be conducted at several locations representing broad categories of wetland types in USEPA Region V. These studies will be conducted over a period of at least two years, and will be designed to address issues identified for each site in Phase I.

Section 2.0 of this report summarizes the major issues identified as a result of the Phase I scoping process. Section 3.0 provides an overview of the relevant literature concerning wetland ecology and the effects of wastewater application to wetlands, and discusses potential impacts in each issue category. An outline of scientific methods available for determining these impacts, and a list of suggested research programs, are presented in Appendix A that accompanies this report. Appendix B presents a summary of practical points concerning use of wetlands for advanced treatment. This list of precautions was amplified by Dr. Robert Kadlec and USEPA Region V and is based on the current knowledge concerning wetland effects of wastewater on wetlands. Sections 4.0. presents an inventory of existing wetlands in Region V that currently receive wastewater discharges and thus constitute sites at which detailed studies could be conducted. An annoted bibliography, listing sites at which wetlands are being used specifically for purposes of wastewater treatment is currently being prepared by Hammer and Kadlec (in preparation). This information is not included in the present report. In section 5.0., suggested study topics are outlined and priorized based on identified the major issues identified. Section 6.0 outlines the future studies to be done and the preparation of the Generic EIS.

1.2 Historical Background

The use of wetlands as a means of treating municipal wastewater represents a relatively recent historical development in the United States. However, the ability of wetlands to purify water has long been recognized For example, natives of the Sudan have used clay soils and indigenous wetland plants to purify Nile River water during the flooding season for generations (Al Azharia Jahn 1976). Beadle (1932) showed that African lakes with no adjacent wetlands were characterized by poorer water quality than lakes bordered by wetlands, indicating a filtering or purifying effect. Pioneering research in Germany since 1953 by Seidel (1976) has clearly demonstrated the ability of aquatic vascular plants to purify wastewater. These and other studies have demonstrated that wetlands are natural filters for many types of pollutants, including sediments, suspended solids and various toxic substances (LaRoe 1983). Eventually, engineers aware of this property of wetlands suggested that they be used for the treatment of wastewater, through the manipulation of the rate and timing of applications and other techniques. The use of wetlands to treat wastewater in this manner has been justified primarily on the basis of cost and treatment effectiveness. For example, in many small rural communities, the cost of building new treatment facilities that will meet the relatively stringent water quality standards promulgated under the Clean Water Act (PL 92-500) may be prohibitive. Wetland treatment systems, in which secondarily treated effluent is passed through a wetland as a final "polishing" step, may be a feasible cost-effective means of meeting such standards. In other cases, discharge to a wetland system is requested because the cost of routing the effluent elsewhere is prohibitive.

As a result of the interest shown in the wetland treatment alternative by various individuals and communities, several studies have recently been conducted in which the problem has been examined in more detail. The objective of these studies has been:

- To assess the wastewater treatment potential of various types of natural and constructed wetlands, especially their efficiencies in removing nutrients from secondarily treated wastewater effluent;
- To assess the environmental impacts on the structure and function of wetland ecosystems and on human health;
- To assess engineering design concepts and management practices for process optimization and potential treatment system breakdown;
- To assess cost-effectiveness including considerations of capital investment, operation, and maintenance costs, cost of detrimental effects, potential for resource recovery, energy recycling, and production of useful byproducts; and
- To assess the enabling policy and legislation, changes in land use, and public attitudes towards the wetland disposal/ treatment issue.

A summary of the major sites at which wetland treatment has been used as an alternative is given in Table 1.2-1. In the United States the most extensive work has been conducted at the Houghton Lake Michigan peatland site by Kadlec et al. Most studies to date, however, have been site-specific, so that adequate generalizations cannot be made to other areas and situations Fur-

Table 1.2-1 Summary of information concerning wetland sites in the U.S. and else where which have been used for advanced treatment of applied wasteland (frcm Hammer and Kadlic in preparation).

Name/Location of Site	Dates of Operation	Annual Discharge Rate (gallons)	Discharge Schedule	Size of Wetland	Estimated Size Affected Area	Types of Studies Advanced	
						Qualitative	Quantitative
Bellaire, Michigan	1972 to Present [c]	30×10^6	May through Oct.	40 acres	30 acres	Vascular plants Algae	--
Bradford, Ontario	1979 to Present[d]	0.5×10^6	Continuous	900M^2	900M^2	--	Vascular plants microorganisms Sediments Litter Soil
Brillion, Wisconsin	1925 to Present[d]	98.3×10^6	Continuous	385 acres	300 acres	--	Vascular plants
Brookhaven, New York	Spring '73-Jan. '79[c]	3(mm)	Continous	0.4 acres	0.4 acres	Sediments	Vascular plants
Clermont, Florida	1977 to 1979[d]	4×10^6	Periodic (water applied over[a] 24 hr. period 1/wk)	32 ha.	6000M^2	--	Vascular plants Algae Soil
Cootes Paradise, Ontario	1920 to Present[d]	Not Available	Continuous	5.2 km^2	1.7 km	--	Vascular plants Sediments Soil
Drummond, Wisconsin	1979 to Present[d]	15×10^6	May through Oct.	27 acres	20 acres	--	Vascular plants Litter Soil
Dulac, Louisiana	1973 to Present[b]	33,150	Bi-weekly	170 ha	0.03 ha	--	Vascular plants Microorganisms
Gainesville, Florida	1973 to Present[d]	6×10^6	Continuous	1.5 ha	1.5 ha	--	Vasular plants Vertebrates Invertebrates Microorganisms Viruses Sediments Litter Soil Human Use Land Use

*Current as of (a) 1972, (b) 1976, (c) 1979, (d) 1981.

2 of 3

Table 1.2-1 Summary of information concerning wetland sites in the U.S. and else where which have been used for advanced treatment of applied wasteland (from Hammer and Kadlic in preparation).

Name/Location of Site	Dates of Operation	Annual Discharge Rate (gallons)	Discharge Schedule	Size of Wetland	Estimated Size Affected Area	Types of Studies Advanced Qualitative	Types of Studies Advanced Quantitative
Great Meadows, Massachusetts	1912(?) to 1980^{d}	1.6×10^{9}	Continuous	54 acres	54 acres	Vascular plants Sediments	Invertebrates
Hamilton Marghes, Delaware	1975 to 1977^{d}	1.7×10^{6}	April through Oct.	500 ha	200 M^{2}	--	Vascular plants Algae Litter Soil
Hay River, Northwest Territories	1965(?) to Present^{d}	11×10^{6}	Continuous	47 ha	32 ha	--	Vascular plants Invertebrates
Houghton Lake, Michigan	1975 to Present^{d}	100×10^{6}	May through Sept.	1700 acres	100 acres	--	Vascular plants Vertebrates Invertebrates Algae Microorganisms Viruses Sediments Litter Soil Human Use Land Use
Humboldt, Saskatchewan	1979 to Present^{d}	$5\text{-}8 \times 10^{6}$	Batch to Adequate Treatment	1 ha	1 ha	Algae Microorganisms	Vascular plants Algae Microorganisms
Jasper, Florida	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Kesålahti, Finland	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Kinross, Michigan (Kincheloe)	1955 to Present^{6}	150×10^{6}	Continuous	500 acres	400 acres	--	Vascular plants Sediments Litter Soil

*Current as of (a) 1972, (b) 1976, (c) 1979, (d) 1981.

3 of 3

Table 1.2-1 Summary of information concerning wetland sites in the U.S. and else where which have been used for advanced treatment of applied wasteland (from Hammer and Kadlic in preparation).

Name/Location of Site	Dates of Operation	Annual Discharge Rate (gallons)	Discharge Schedule	Size of Wetland	Estimated Size Affected Area	Types of Studies Advanced Qualitative	Types of Studies Advanced Quantitative
Lake Balaton, Hungary	Not Available^a	Not Available	Continuous	Not Available	2000 M^2	Not Available	--
Las Vegas, Nevada	? to Present^d	30×10^9	Continuous	800 acres	600 acres	Vertebrates Invertebrates Algae Human Use Land Use	--
Listowel, Ontario	1980 to Present^d	15×10^6	Continuous	2.5 acres	2.5 acres	Vertebrates Invertebrates Algae	Vascular plants Algae Microorganisms Sediments Litter Soil
Mt. View Sanitary District, California	1974 to Present^d	255×10^6	Continuous	21 acres	21 acres	Vascular plants	Vertebrates Invertebrates Vascular plants
Seymour, Wisconsin	1973 to 1975^d	100,000	June through Dec.	112 M^2	112 M^2	--	
Suisun City, California	1977 to 1982^d	5.0×10^6	Oct. 1 through May 15	84,000 acres	300 acres	Vascular plants Invertebrates Algae Soil	Algae
Vermontville, MI	1978 to 1979^d	25×10^6	June through Oct or Nov.	11.5 acres	11.5 acres	--	Vascular plants Vertebrates (No wetland prior to irrigation).
Waldo, Florida	1935 to Present^d	30×10^6	Continuous	2.6 ha	2.6 ha	--	Vascular plants Litter Soil
Wildwood, Florida	1957 to Present^d	55×10^6	Continuous	500 acres	500 acres	Vascular plants	Vascular plants Litter

*Current as of (a) 1972, (b) 1976, (c) 1979, (d) 1981.

thermore, little information is available concerning the detailed mechanisms by which wetlands "treat" applied wastewater, the rates at which the various treatment processes function, and the long-term ability of wetlands to function effectively as treatment systems (Hammer and Kadlec 1982; Kadlec 1978). Finally, no single study has yet successfully integrated available information on: (1) the treatment potentials of different wetland types; (2) the impacts of applied wastewater on wetlands of varying types; and (3) the available options for managing wetland wastewater application systems Basic research in these areas is needed to establish design parameters (and to establish permit limitations) if the wetland alternative is to be utilized in the future (Reed and Kubiak 1983). However, few studies of this nature have been done to date, and there are major data deficiencies in scientific knowledge concerning this subject (Hammer and Kadlec 1983; Heliotis 1982).

The objective of the present study is to establish the basis for more detailed research concerning the effects of wastewater applications to wetlands in USEPA Region V. This effort represents the first step in obtaining the data needed to understand the effect of wastewater discharges, the degree of treatment achieved, and the best means of managing such systems. This type of information will be required in order for USEPA Region V, and associated Federal and state review agencies, to make informed permit decisions concerning wetland wastewater application alternatives in the future.

1.3 Definition of the Term "Wetland"

To aid the reader in the sections that follow, the term "wetland" first needs to be defined. To simplify the concept, the present study employs the broadest possible definition of the term. As formulated by Cowardin et al. (1979), that definition is as follows:

> "Wetlands are lands transitional between terrestrial and aquatic ecosystems where the water table is usually at or near surface and the land is covered by shallow water. . . wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of the year."

Wetlands can thus include a variety of ecosystems ranging from seasonally flooded bottomland swamp forests to permanently flooded cattail marshes. Peatlands, bogs, swamps, sedge meadows, fens, and potholes would all be included as wetlands under this broad definition.

Cowardin et al. (1979) also provided a classification scheme for wetlands based on major "modifiers," including dominant vegetation, soil characteristics, and frequency of flooding (Figure 1.3-1). Five overall types of wetland systems--Marsh, Estuarine, Riverine, Lacustrine, and Palustrine--were established by Cowardin et al. (1979). The latter three types occur in USEPA Region V. Each system is further subdivided into subsystems and classes (Figure 1.3-1). Figures 1.3-2 through 1.3-4 illustrate the further subdivisions of each major subsystem into the various classes of wetlands as defined by Cowardin et al. (1979). These classifications are used in Section 4.0 of this report to define the types of wetlands inventoried in Region V.

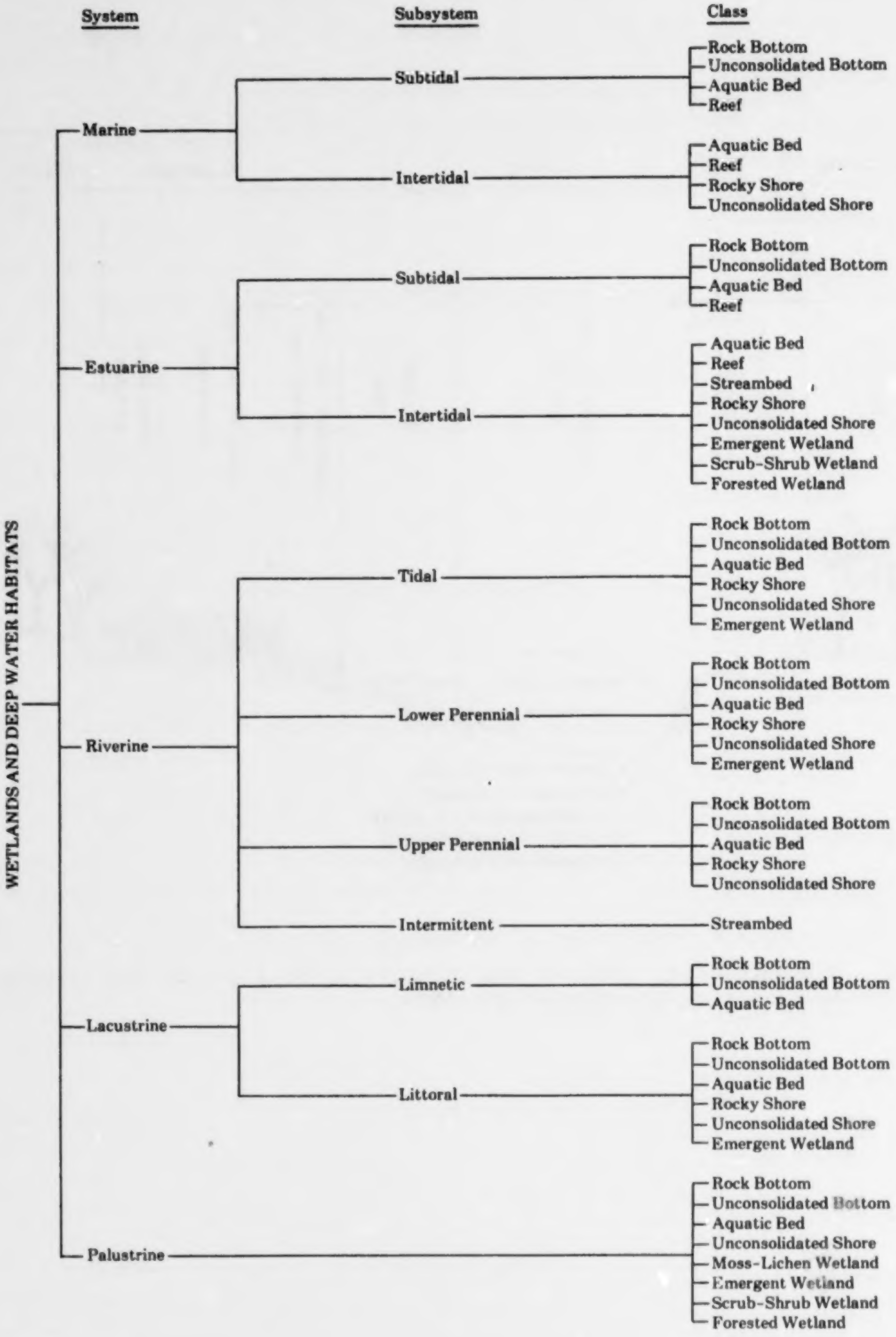
System
Subsystem
Class
WETLANDS AND DEEP WATER HABITATS
Marine
Subtidal
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Reef
Intertidal
Aquatic Bed
Reef
Rocky Shore
Unconsolidated Shore
Estuarine
Subtidal
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Reef
Intertidal
Aquatic Bed
Reef
Streambed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Scrub-Shrub Wetland
Forested Wetland
Riverine
Tidal
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Lower Perennial
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Upper Perennial
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Intermittent
Streambed
Lacustrine
Limnetic
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Littoral
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Palustrine
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Unconsolidated Shore
Moss-Lichen Wetland
Emergent Wetland
Scrub-Shrub Wetland
Forested Wetland

Figure 1.3-1. USFWS Classification hierarchy of wetlands and deepwater habitats, showing systems, sub-systems and classes (from Cowardin et al. 1979)

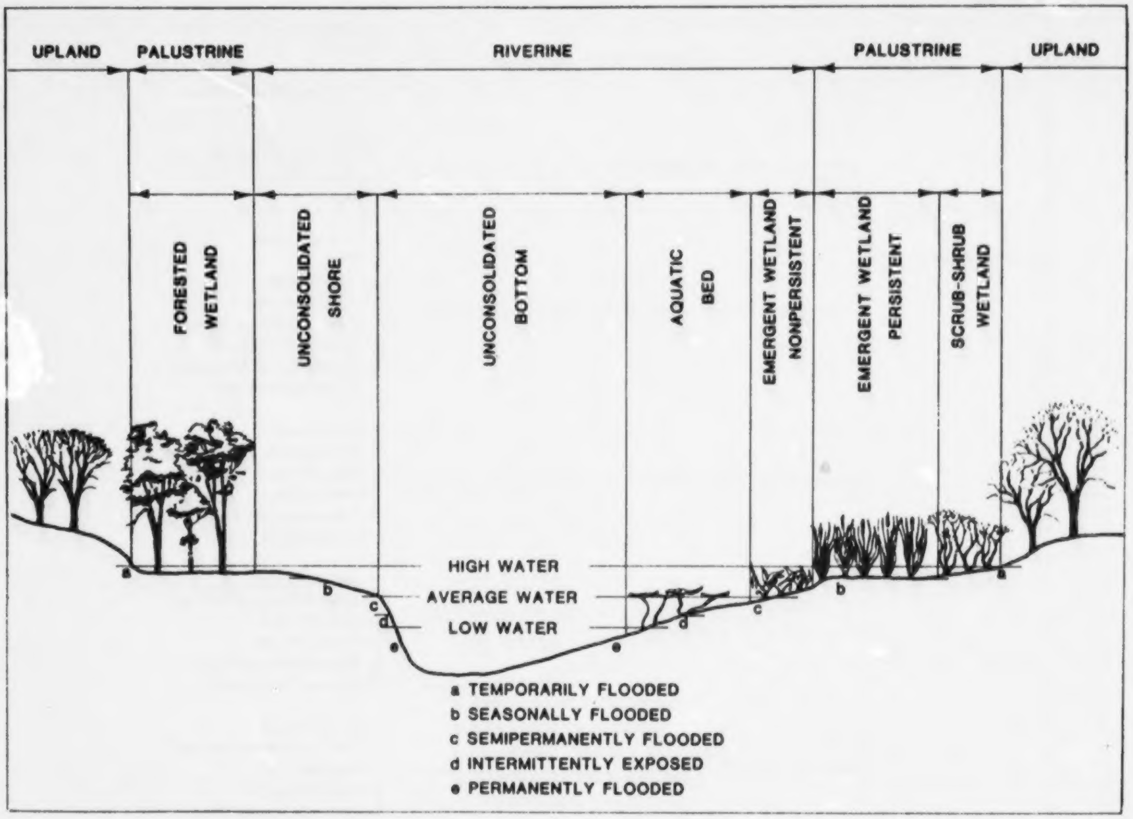
UPLAND
PALUSTRINE
RIVERINE
PALUSTRINE
UPLAND
FORESTED WETLAND
UNCONSOLIDATED SHORE
UNCONSOLIDATED BOTTOM
AQUATIC BED
EMERGENT WETLAND NONPERSISTENT
EMERGENT WETLAND PERSISTENT
SCRUB-SHRUB WETLAND
HIGH WATER
AVERAGE WATER
LOW WATER
a
b
c
d
e
a TEMPORARILY FLOODED
b SEASONALLY FLOODED
c SEMIPERMANENTLY FLOODED
d INTERMITTENTLY EXPOSED
e PERMANENTLY FLOODED

Figure 1.3-2. Distinguishing features and examples of habitats in the Riverine System (from Cowardin et al. 1979).

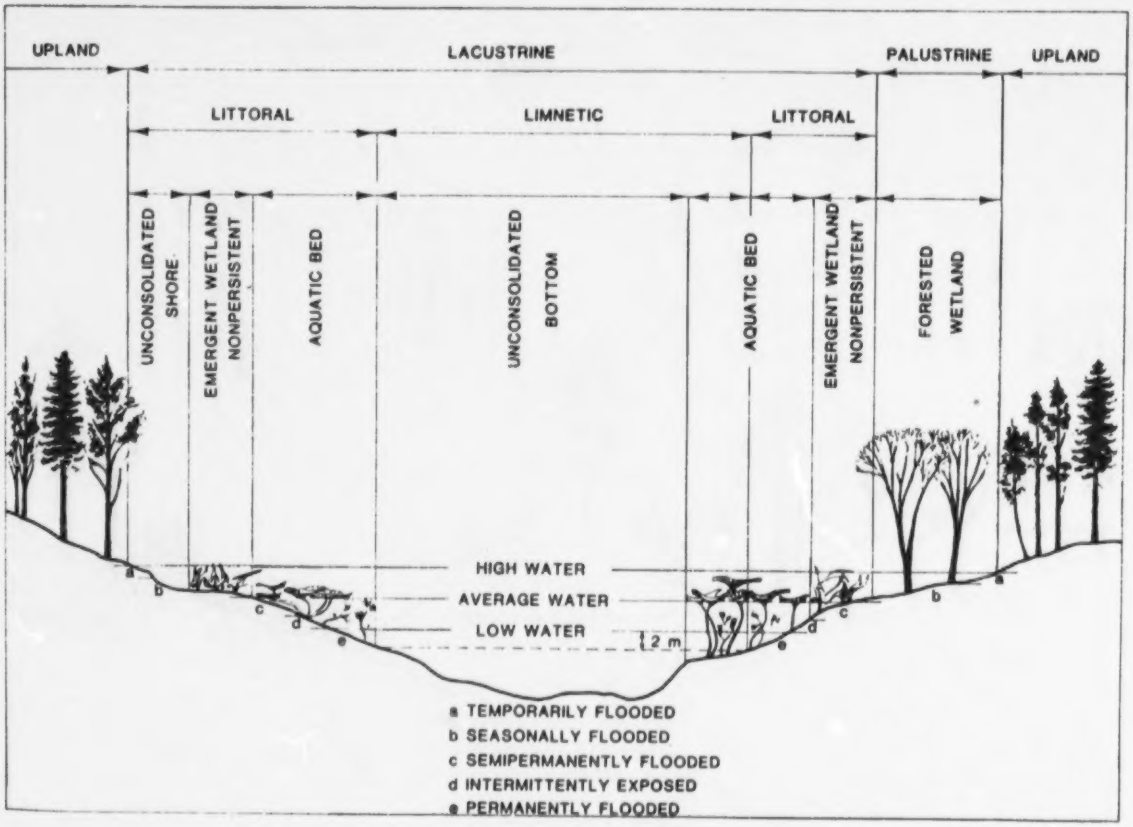
UPLAND
LACUSTRINE
PALUSTRINE
UPLAND
LITTORAL
LIMNETIC
LITTORAL
UNCONSOLIDATED SHORE
EMERGENT WETLAND NONPERSISTENT
AQUATIC BED
UNCONSOLIDATED BOTTOM
AQUATIC BED
EMERGENT WETLAND NONPERSISTENT
FORESTED WETLAND
HIGH WATER
AVERAGE WATER
LOW WATER
2 m
a
b
c
d
e
e
d
c
b
a
a TEMPORARILY FLOODED
b SEASONALLY FLOODED
c SEMIPERMANENTLY FLOODED
d INTERMITTENTLY EXPOSED
e PERMANENTLY FLOODED

Figure 1.3-3. Distinguishing features and examples of habitats in the Lacustrine System (from Cowardin et al. 1979).

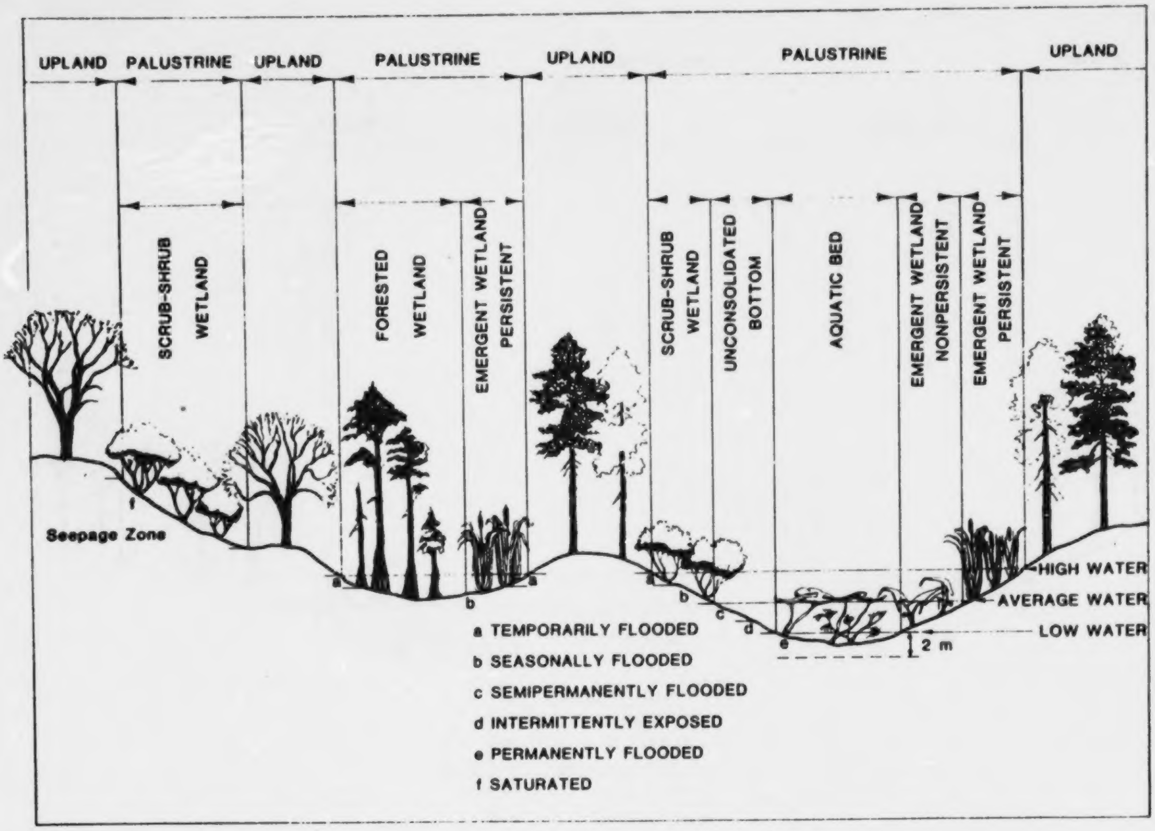
UPLAND
PALUSTRINE
UPLAND
PALUSTRINE
UPLAND
PALUSTRINE
UPLAND
SCRUB-SHRUB WETLAND
FORESTED WETLAND
EMERGENT WETLAND PERSISTENT
SCRUB-SHRUB WETLAND
UNCONSOLIDATED BOTTOM
AQUATIC BED
EMERGENT WETLAND NONPERSISTENT
EMERGENT WETLAND PERSISTENT
Seepage Zone
f
a
b
a
a
b
c
d
e
HIGH WATER
AVERAGE WATER
LOW WATER
2 m
a TEMPORARILY FLOODED
b SEASONALLY FLOODED
c SEMIPERMANENTLY FLOODED
d INTERMITTENTLY EXPOSED
e PERMANENTLY FLOODED
f SATURATED

Figure 1.3-4. Distinguishing features and examples of habitats in the Palustrine System (from Cowardin et al. 1979).

2.0 SUMMARY OF ISSUES

2.1 Listing of Issues

At the initiation of this planning study, EPA listed issues to be investigated during the Phase II study. This list is presented as the major headings in Table 2.1-1.

2.2 Scoping Process

Because the present study was initially intended to be the first stage of a project that would culminate in the preparation of an EIS, an EIS scoping meeting was held in Madison, Wisconsin, on 2 October 1980, for the following purposes:

- To present an overview of the EIS process and the content of the proposed EIS to all interested agencies, organizations, and citizens;
- To provide an opportunity for input from these groups to the EIS process; and
- To define the issues and problems associated with the topic of application of treated wastewater to wetlands as accurately as possible.

Approximately 50 persons, including representatives from a number of Federal and state agencies, universities, and environmental and public interest groups, attended the meeting. Written comments also were submitted to EPA by persons unable to attend the meeting. The majority of these comments were from state agency personnel located in other states in Region V.

After the presentation of the format and content of the study by EPA personnel, those attending separated into discussion groups to further identify and categorize of issues. The results of these discussions, as well as comments and recommendations offered by individuals, were recorded and submitted to USEPA. These comments and recommendations were reviewed and added to make a list of general issues. Related issues were then expanded upon and grouped into general categories. The results of this task are presented in Table 2.1-1.

Table 2.1-1. Specific issue categories and areas of concern.

WETLAND STRUCTURE AND FUNCTION CONSIDERATIONS

- What are the different relationships between a particular wetland discharge and local surface water and groundwater resources, and what potential effects could occur on these resources, such as:
  - Raising of local water table;
  - Increased level of nutrients or other substances;
  - Reduced flood storage capacity?
- What are the possibilities of a wetland affected by a wastewater discharge returning to the pre-discharge condition (i.e., are the changes chronic and cumulative, or temporary and reversible)?
- Can the status of a wetland be maintained in the presence of wastewater discharge, with regard to:
  - Floodwater storage
  - Effects on soils and sediments
  - Effects due to accumulation of dissolved substances, trace metals, or chemicals?
- What are the relationships of treatment effectiveness to daily, seasonal and long-term ecological cycles in different types of wetlands?
  - Does the addition of treated wastewater increase the rate of eutrophication;
  - Does the addition of treated wastewater increase the rate of succession;
  - What is the rate of change in each type of wetland;
  - Does the addition of treated wastewater enhance the growth of undesirable species?
  - Can the status of fish and wildlife be maintained?
- What are the effects and long-term impacts of the discharge of treated wastewater on the structure and function of different types of wetlands in EPA Region V?
  - What are the effects of changes in temperature, pH, nutrient levels, flow rates, soil types, and hydrologic patterns?
  - Will these result in:
    - Changes in species composition and diversity
    - Effects on endangered and threatened species;
    - Decreases in populations of desirable species?
- What indicator species can be used to identify the development of adverse effects from discharge?

POTENTIAL FOR ENHANCEMENT AND MANAGEMENT OF WILDLIFE AND WILDLIFE HABITAT

- What species can be enhanced in association with the use of a natural wetland for treatment of treated wastewater?

- What species can be enhanced in association with the operation of a constructed wetland treatment system?

- What management techniques are feasible for the enhancement of each of the species identified? What will be the secondary effects of the implementation of these actions?

- What agency (agencies) will manage wetland treatment systems that have been designated as being used for enhancement of wildlife and wildlife habitat?

  - How would funds be provided for this purpose?
  - How long would such areas be required to be managed?
  - Should such areas be managed for a particular species?

- What type of restoration of disturbed wetlands is possible? How can this be done effectively?

HEALTH CONSIDERATIONS

- What are the implications for adverse effects on the health of humans, plants, and wildlife, such as:

  - Exposure to or consumption of contaminated organisms;
  - Enhancement of populations of pests, such as mosquitoes, that may transmit diseases;
  - Increase in type and number of parasites, bacteria, and viruses;
  - Increased levels and possible bioaccumulation of toxic organic and inorganic substances, including:

    - Heavy metals;
    - Ammonia;
    - Surfactants;
    - Detergents;
    - Refractory chemicals;
    - Trihalomethances?

OVERLOADING AND STRESS CONDITIONS

- What are the impacts on the structure and function of a wetland receiving a discharge from a facility bypass or malfunction due to:

  - Excessive levels of nutrients;
  - Hydraulic overloading;
  - Mechanical failure;
  - Destruction of biological process organisms by toxins or other means?

DESIGN, OPERATION, AND MONITORING CONSIDERATIONS FOR A NATURAL WETLAND TREATMENT SYSTEM

- What kind of wetlands are best suited for treatment of wastewater from the standpoint of effectiveness? What kinds are not suitable, based on:
    - Hydrologic types;
    - Vegetation types;
    - Soil types?
- What are the design criteria for an acceptable and effective wetland discharge, such as:
    - Size of wetland;
    - Type and level of pretreatment required?
    - Loading rate;
    - Volume of discharge;
    - Application methods (spray, gated pipe, etc.) and the value of each type for use in different types of wetlands or under different conditions;
- How can existing treatment facilities be converted to incorporate a wetland treatment component?
- What percent of the wetland is necessary as a buffer zone for avoidance of impacts or bypass of facility?
- What maintenance techniques should be used for each types of system?
- What type of monitoring should be performed, including:
    - Parameters to be measured;
    - Timing and frequency of monitoring, especially for winter operations;
    - Location of sampling stations, particularly for determination of compliance with water quality standards?
- What indicator species can be used to monitor wetland discharge sites?

CONSTRUCTED WETLANDS

- What is the feasibility of construction of wetlands for treatment of wastewater in various parts of Region V, especially in areas where soils are not suitable for septic tanks and the population level is insufficient to justify construction of a centralized treatment system?
- What is the effectiveness of treatment with different:
    - Climatic or discharge conditions;
    - Vegetation types including those suitable for harvest;
    - Soil substrate types?
- What are the benefits of using constructed wetlands for the treatment of wastewater, as opposed to using natural wetlands?

- What are the problems involved in the conversion of existing facilities to include wetland treatment by constructed wetlands?

MITIGATION

- What mitigative measures can be taken to avoid impacts on wetlands from:

    - Operation of conventional treatment facilities;
    - Primary impacts;

        - Siting of facilities;
        - Construction and operation of conventional facilities;
        - Construction of interceptors and pumping stations;
        - Discharges to wetlands;
        - Problems associated with use of lagoons by wildlife;

    - Secondary impacts;

        - Induced development;
        - Increased human use of area;

    - Innovative and alternative technologies;

        - Construction of wetland treatment systems;
        - Other land treatment methods that could affect wetlands?

- What types of impacts cannot be avoided or mitigated effectively, and would require that alternative actions be taken?

LEGAL, ADMINISTRATIVE, AND REGULATORY CONSIDERATIONS

- What are the present federal and state regulations applicable to:

    - Definition of wetlands and wetland boundaries;
    - Use of natural wetlands for wastewater treatment, including: use situations involving wetlands, including:
        - Levels and types of pretreatment required;
        - Mandatory disinfection;
        - Industrial wastewater;
    - Water quality standards related to wetland discharge/treatment;
    - Creation of wetlands;
    - Maintenance of volunteer wetlands;
    - Procedures for upgrading of facilities to convert to wetland treatment;
    - Use of treated wastewater to improve wildlife habitat, particularly on public land?

- What are the potential conflicts between jurisdictions relating to the protection of wetlands at various governmental levels and between different states in Region V:

    - Regional planning and 208 interface;
    - Water law and regulatory inferface?

- What are the implications of these conflicts for the development of innovative and alternative technologies involving the use of natural and constructed wetlands for wastewater treatment?

- What new institutional arrangements need to be made to permit the:

    - Use of natural wetlands for wastewater treatment;
    - Creation of constructed wetlands for wastewater treatment;
    - Maintenance of volunteer wetlands for wastewater treatment;
    - Restoration of wetlands;
    - Destructive testing to determine assimilative capacity;
    - Prevention of illegal discharges to wetlands used as treatment sites?

- What types of permit approvals are required?

- What types of wetlands should be designed as suitable for wastewater treatment? In what areas?

- What policies should be developed for the use of areas recognized as exhibiting specific values or that have designated management goals:

    - Buffer areas;
    - Preservation of an area of sufficient size for effective treatment?

- Is the use of natural wetlands for wastewater treatment consistent with Federal or state regulations or interagency agreements on protection of wetlands?

    - Under what circumstances is a wetland considered to be part of the treatment system? Is an NPDES permit required for this discharge?
    - Is a wetland discharge considered to be "land treatment" or "discharge to the waters of the United States"?
    - Does a change in habitat type or a loss of species as a result of the introduction of wastewater into a wetland constitute a violation of Section 101 of the Clean Water Act?
    - What criteria should be developed to identify wetlands as suitable for wastewater treatment?
    - Is the concept (and associated regulatory requirements) of a mixing zone applicable?
    - How would failure of the wetland as a functional treatment site be defined? What actions should be taken in the event of failure?

- Is the acquisition of a wetland for wastewater treatment purposes a grant-eligible cost?

- What legal problems might be associated with wetland treatment sites, such as in the areas of:

    - Restriction of public use of the site for recreation or harvest;
    - Landowner use of the site;
    - Engineering liability related to design, operation, and maintenance;
    - Multiple use of a publicly owned, operated, or managed site?

- What is the public acceptability of the use of natural wetlands for the treatment of wastewater?

3.0 LITERATURE REVIEW

This section summarizes the status of the current scientific literature concerning each issue identified in Section 2.0. The literature review considers the importance of each issue and the results of relevant studies that have been conducted or that are ongoing. Suitable methods and programs available to address each issue are presented in Appendix A (Technical Support Document). The information in Appendix A is intended for use as a guide and reference to available methods and research approaches. Specific methods and research programs have been developed in detail for individual sites, and are presented in Section 4.0 of this report.

3.1 Issue Category I: Wetland Structure and Function - Physical and Chemical Components

3.1.1 Effects on Site Hydrology

3.1.1.1 Role of Hydrology in Wetlands

The hydrologic regime is the single most important factor that affects the ecological, physical, and chemical characteristics of wetland systems (Gosselink and Turner 1978; Novitzki 1978). Factors that influence the hydrologic cycle include surface water and groundwater inputs, direct atmospheric precipitation, and losses through evapotranspiration (Figure 3.1-1). The hydrogeological setting of a wetland ultimately determines the volume of the water flowing through the system and its chemical composition. The volume of water entering and leaving a wetland, and its mineral content, in turn, are determined by the net balance of each of the above factors (Heliotis 1982). Effective water quality management therefore requires knowledge of hydrological conditions because of the central role of the hydrologic regime in wetland ecology. The hydrologic regime may also be readily amenable to manipulation for purposes of water quality management. The following description provides an overview of the role of the hydrologic cycle in wetland ecology.

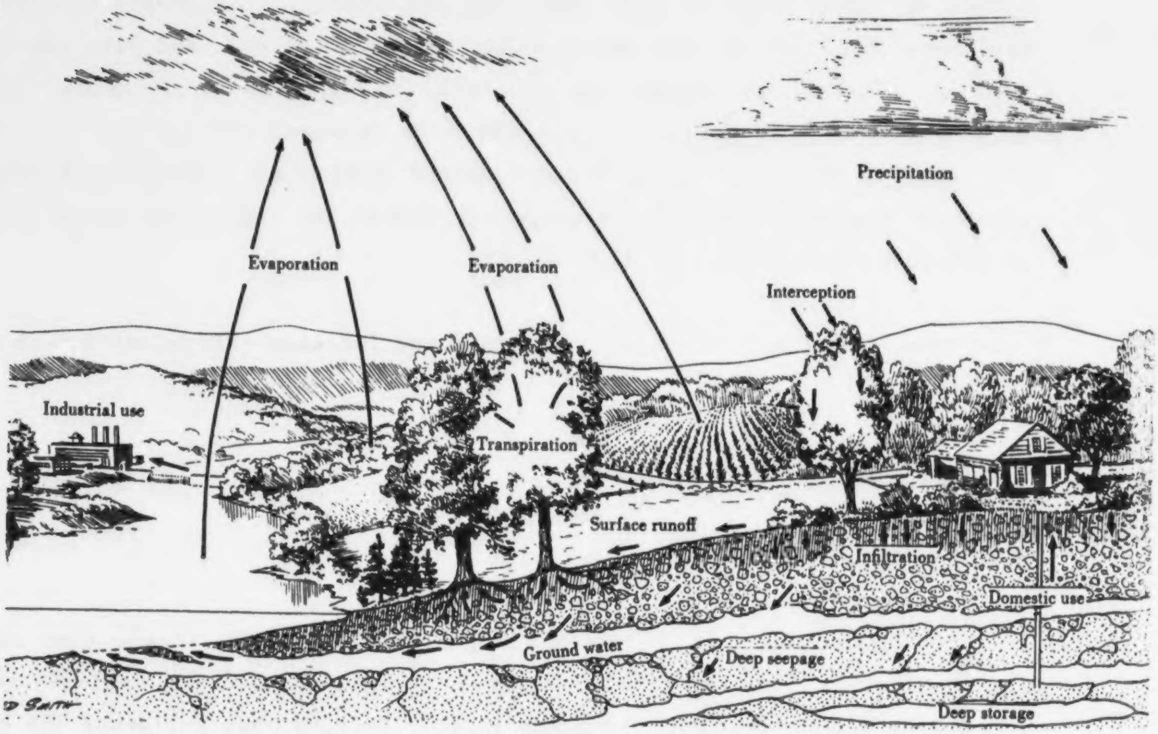
Precipitation
Evaporation
Evaporation
Interception
Industrial use
Transpiration
Surface runoff
Infiltration
Domestic use
Ground water
Deep seepage
Deep storage

Figure 3.1-1. The hydrologic cycle (from Smith 1966).

Groundwater is an important source of water and minerals for many wetlands. The configuration of the water table, and the hydraulic conductivity of the underlying substrate, determine the interaction of groundwater with wetlands. Bedford et al. (1974) characterized these interactions as being of four general types:

- The wetland is a recharge area and the groundwater moves up towards the water table;
- The wetland is a discharge area and the water moves from the wetland to the aquifer;
- The wetland is perched or above the water table, but its basin is sealed with clay, thus preventing direct connection with the water table; and
- The wetland is a flow-through area in which the water table slopes into some part of the basin and away in the remainder, thereby producing simultaneous inflow and outflow.

Surface water may enter a wetland in the form of streamflow or as overland flow from adjacent areas. Overland flow is an important source of nutrients, but is difficult to measure accurately (Carter et al. 1978 and Huff et al. 1973). The rate and volume of surface flow is a function of the size of the watershed, its slope, and the hydraulic permeability of the upland soils. The water quality of wetlands that depend primarily on surface water for their existence varies with high and low water conditions (Novitzki 1981). Surface water quality is largely determined by land use and soil types. Novitzki (1978) divided Wisconsin's wetlands, which are typical of Region V wetlands, into the following four hydrologic classes:

- Surface water depression wetlands - water entering leaves only by leakage into the ground or by evapotranspiration (Figure 3.1-2);
- Surface water slope wetlands - receive water from lake or river flooding; water can readily drain back to the lake or river, as stages fall (Figure 3.1-3);
- Groundwater depression wetlands - have contact with the water table and no surface drainage away from the site (Figure 3.1-4); and

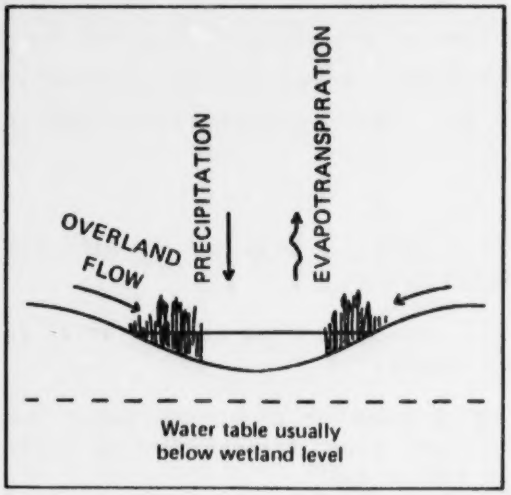
OVERLAND FLOW
PRECIPITATION
EVAPOTRANSPIRATION
Water table usually below wetland level

Figure 3.1-3. Hydrologic characteristics of surface water slope wetlands (from Novitzki 1978)

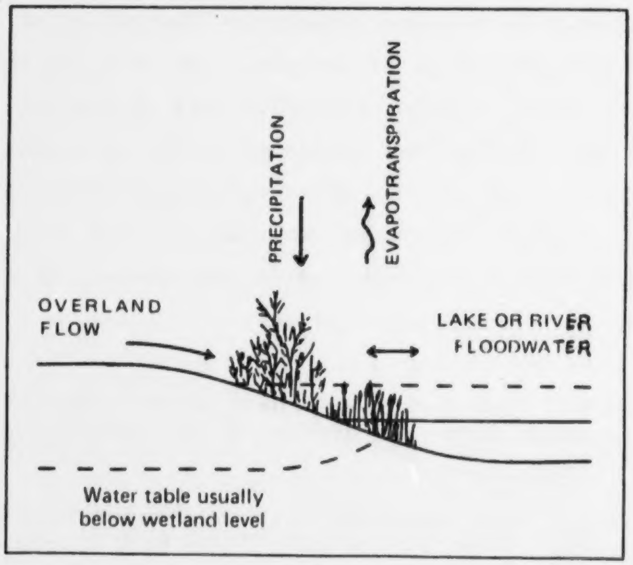
PRECIPITATION
EVAPOTRANSPIRATION
OVERLAND FLOW
LAKE OR RIVER FLOODWATER
Water table usually below wetland level

Figure 3.1-2. Hydrologic characteristics of surface water depression wetlands (from Novitzki 1978)

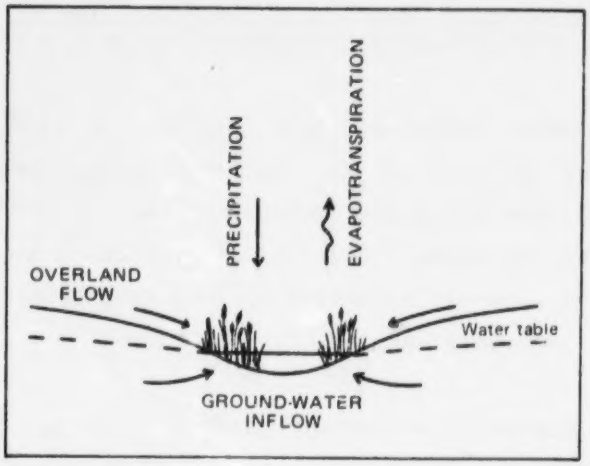
PRECIPITATION
EVAPOTRANSPIRATION
OVERLAND FLOW
Water table
GROUND-WATER INFLOW

Figure 3.1-4. Hyrologic characteristics of groundwater depression wetlands (from Novitzki 1978).

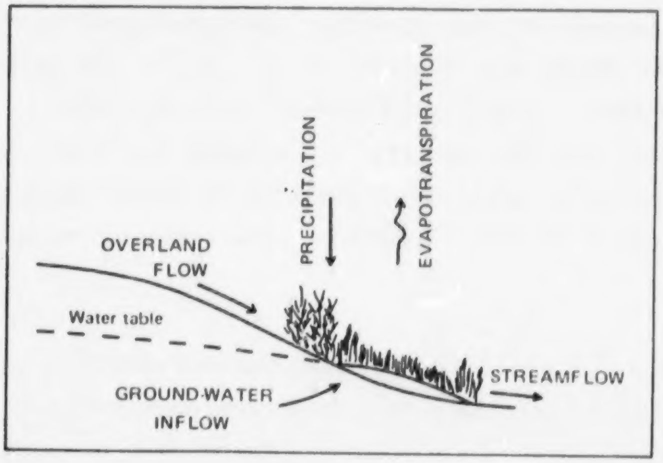
PRECIPITATION
EVAPOTRANSPIRATION
OVERLAND FLOW
Water table
GROUND-WATER INFLOW
STREAMFLOW

Figure 3.1-5. Hydrologic characteristics of groundwater slope wetlands (from Novitzki 1978).

- Groundwater slope wetlands - constant groundwater discharge and an opportunity for surplus water to flow downslope away from the site, eliminating ponding (Figure 3.1-5).

Because plant species differ in their tolerance of flooding, different plant communities occur in each of the four hydrologic classes. Figures 3.1-6, 3.1-7, and 3.1-8 show how plant communities vary according to each hydrologic class in Wisconsin wetlands. Clearly, alteration of the existing hydrologic regime, as in the case of wastewater application, is very likely to result in changes in plant community species composition.

Wastewater applied to a wetland, depending on its flow and composition, can greatly alter the hydrologic regime and nutrient exchange. Heliotis (1982) discussed the necessity for assessing the relationship between surface water and wetlands receiving wastewater because runoff from unusual storms could flood the wetland and flush effluents into water bodies nearby. The differing characteristics of each of the above wetland classes largely determine how each type affects flood and base flows. In general, wetlands tend to reduce peak floodflows (Novitzki 1978). The effect of floodwaters on total streamflows depends on the specific hydrogeological setting (Larson 1981, Novitzki 1978, Verry and Boelter 1978). Fritz and Helles (1978) proposed analyzing stormwater runoff of adjacent areas in order to determine possible adverse effects on the ability of wetlands to treat applied wastewater. Excessive stormwater could also potentially cause wastewater to flow more rapidly through a wetland, reducing waste retention times and treatment effectiveness.

The most important input of water for certain types of wetlands is precipitation. This is particularly true for some northern bogs (Kadlec 1976, Moore and Bellamy 1974). Water levels throughout an entire geographic area, as well as water tables in surrounding uplands, can be increased uniformly by precipitation. Precipitation slowly adds to the subsurface inflow, and rapidly adds to the stream inputs to the wetland (Kadlec 1976). Precipitation is also a mineral source for wetlands (Gorham 1961).

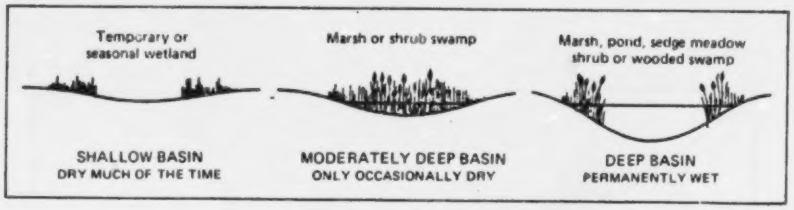
Temporary or
seasonal wetland
Marsh or shrub swamp
Marsh, pond, sedge meadow
shrub or wooded swamp
SHALLOW BASIN
DRY MUCH OF THE TIME
MODERATELY DEEP BASIN
ONLY OCCASIONALLY DRY
DEEP BASIN
PERMANENTLY WET

Figure 3.1-6. Different plant communities in surface water depression wetlands related to water permanence and basin depth (from Novitzki 1978).

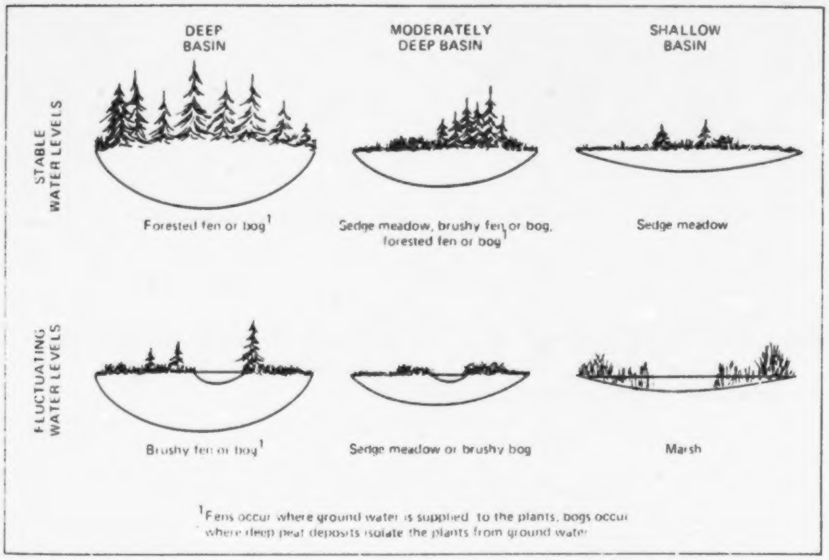
DEEP
BASIN
MODERATELY
DEEP BASIN
SHALLOW
BASIN
STABLE
WATER LEVELS
Forested fen or bog[1]
Sedge meadow, brushy fen or bog,
forested fen or bog[1]
Sedge meadow
FLUCTUATING
WATER LEVELS
Brushy fen or bog[1]
Sedge meadow or brushy bog
Marsh
[1]Fens occur where ground water is supplied to the plants, bogs occur
where deep peat deposits isolate the plants from ground water

Figure 3.1-7. Different plant communities in groundwater depression wetlands related to basin depth and groundwater level fluctuations (from Novitzki 1978).

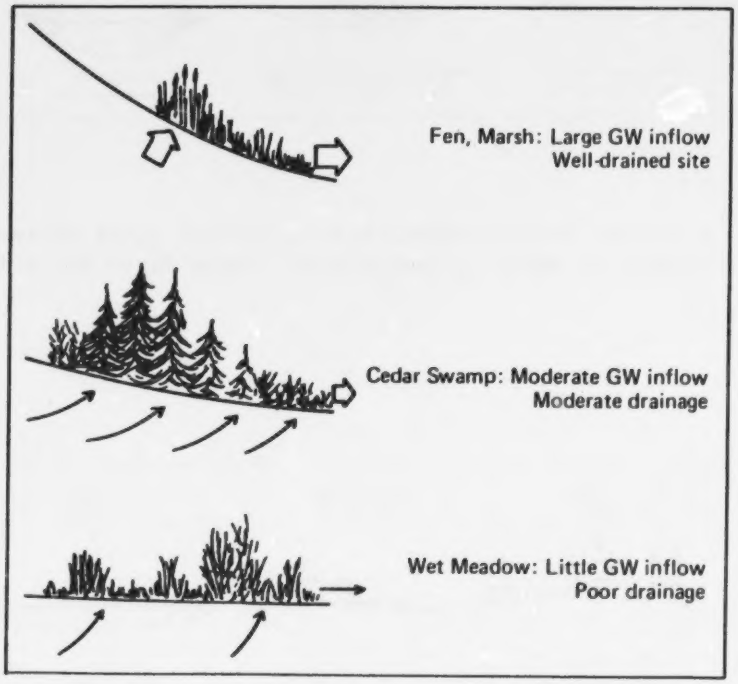
Fen, Marsh: Large GW inflow
Well-drained site
Cedar Swamp: Moderate GW inflow
Moderate drainage
Wet Meadow: Little GW inflow
Poor drainage

Figure 3.1-8. Different plant communities in groundwater slope wetlands related to groundwater inflow and drainage (from Novitzki 1978).

Evapotranspiration removes water from a land or water surface, the unsaturated zone, or the saturated zone, and typically accounts for 37% to 93% of water loss from wetlands (Novitzki 1978). Reduced amounts of water can increase the concentration of nutrients, thereby affecting water quality.

The net balance of the above factors (surface and groundwater inflow and outflow, precipitation, and evapotranspiration) determines the hydrologic regime of individual wetlands. However, due to the varying influences of each factor in different geologic settings and geographic areas, hydrologic regimes vary greatly between different types of wetlands (Figure 3.1-9). These differences need to be taken into account if wetland wastewater application systems are to be effectively managed.

In addition to controlling overall water balance in wetlands, the hydrologic regime also controls wetland soil formation (Figure 3.1-10). In general, organic soils build under low-flow conditions, whereas higher energy environments are characterized by more mineral soils. Alluvial deposition rates and biogenic accumulation rates are also influenced by flow regime. The net balance between flow regime, alluvial deposition, and biogenic accumulation ultimately determines the soil type that develops (Brown et al. 1979). As soils build in response to an individual hydrologic regime, they in turn alter the net balance of water flowing in and out of the wetland by changing current speed and direction of flow and, subsequently, deposition rates. This in turn may alter the types of plants and animals inhabiting the wetland by changing the types of soils as well as the hydroperiod (Figure 3.1-10).

3.1.1.2 Effects of Changes of Wastewater Application on the Hydrologic Regime

Hydrologic factors that must be understood in order to assess the ability of a wetland to treat wastewater include water depth, flooding regime, flow dynamics, and the overall water budget. For example, water depth and flooding regime (timing, extent, and duration) together largely control the abundance and species composition of vegetation, as well as the abundance, distribution, and types of invertebrates and other animal life that inhabit a wetland (Bedinger 1978). Changes in water depth and flooding regime can potentially alter plant species composition, energy flow, and mineral recycling of wetlands, and must be well understood in order to assess the potential impacts of wastewater

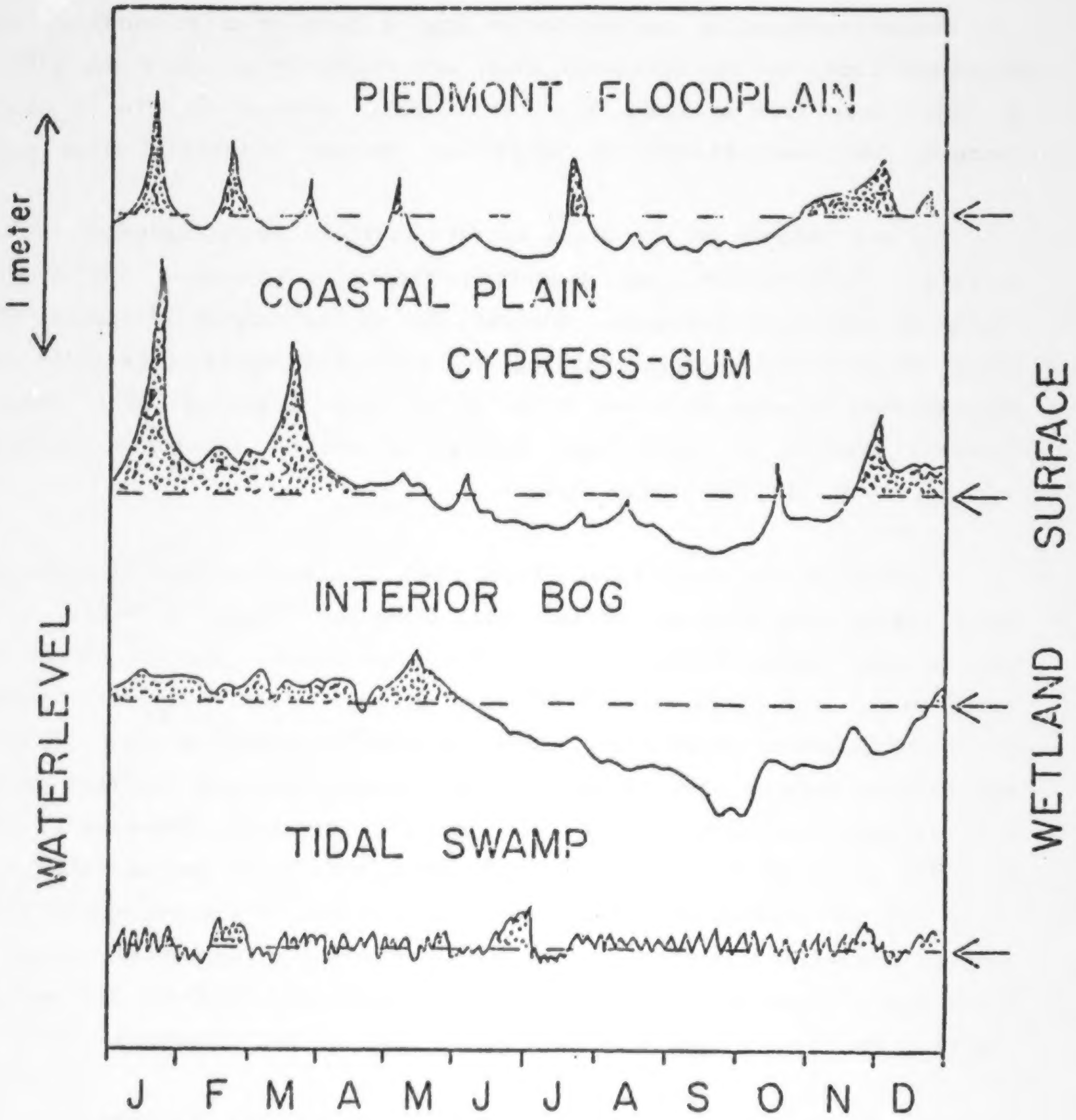

Figure 3.1-9. Hypothetical types of hydroperiods for various wetland types (from Brown et al. 1979).

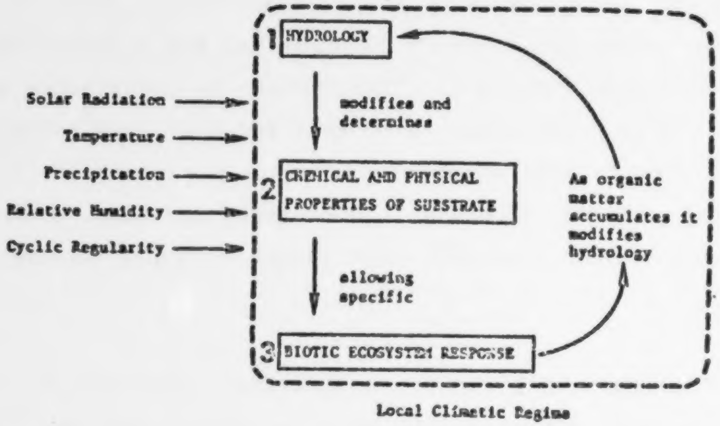
1 HYDROLOGY
Solar Radiation
Temperature
Precipitation
Relative Humidity
Cyclic Regularity
modifies and determines
2 CHEMICAL AND PHYSICAL PROPERTIES OF SUBSTRATE
As organic matter accumulates it modifies hydrology
allowing specific
3 BIOTIC ECOSYSTEM RESPONSE
Local Climatic Regime

Figure 3.1-10. General conceptual model illustrating the role of the hydrologic cycle in the ecology of wetland systems (from Gosselink and Turner 1978).

application. Flooding regime also determines the rates of litter decomposition and detrital recycling (Ewel and Odum 1979), which are of central importance in maintaining wetland food webs. Decomposition will be slower in winter under cold temperatures or under conditions of constant flooding, for example. In addition, excessive rainfall may produce increased erosion in a wetland, leading to channelization). This may reduce the treatment effectiveness of a wetland due to a reduction in detention time. Wile etal. (1983) found that a hydraulic loading rate of $200m^3$/ha/day and a detention time of seven days produced optimal treatment effectiveness in constructed wetland at Listowell, Ontario. Wile et al (1983) also observed hydrologic short-circuiting in a large open constructed marsh at Listowell was produced by excessive litter build up and channel blockage. They concluded that a system with numerous shallow sinous channels (with high length to width ratios) produced optimal treatment.

Knowledge of the hydrologic regime is therefore essential to the understanding of the treatment effectiveness of a particular wetland (i.e., the amounts of water and suspended and dissolved solids entering and leaving the wetland per unit time) (Kadlec 1978). Detailed knowledge of the hydrologic regime will allow quantitative analysis of the effectiveness of the wetland in treating the waste, as well as determination of how hydrologic changes might affect vegetation and wildlife.

An example of the interrelated effects of the hydrologic regime on the ability of a wetland to treat wastewater was provided by Bayley (1978), who found that plant growth rates and standing crops in a Florida freshwater wetland receiving treated wastewater were highly dependent on the hydrologic conditions. Chemical cycling was also strongly influenced by water regime. However, the presence or absence of standing water did not significantly affect the ability of the wetland to remove nutrients (Table 3.1-1), since significant amounts of phosphorus and nitrogen were removed in both wet and dry years. Only at very high levels of effluent application (9.6 cm/week as compared with the lower rate of 4.4 cm/week) could differences in vegetation or soil chemistry be detected. However, the vegetation growth rate, standing crop, and tissue phosphorus levels were affected as much by the presence of standing water as by the application rate, whereas tissue nitrogen level was

Table 3.1-1. Annual retention of applied phosphorus and nitrogen in the freshwater marsh plot receiving 9.6 cm wk-1 treated wastewater. Percent removal based on P and N measured in outflow (from Bayley 1983).

Nutrient Measured	Dry Year	Wet Year
Phosphorus		
Well on edge of plot[1]	98.56%	99.31%
Well below effluent pipe	(97.97)	(93.65)
Nitrogen		
Well on edge of plot[1]	71.19%	88.42%
Well below effluent pipe	(62.87)	(85.41)

---

[1] Treatment plot within wetlands.

more related to the application rate. Hydrologic regime was thus shown to have variable and interrelated effects (note that this example is for a non-flow through wetland. Wet years in a flow through wetland typically have the opposite effect, reducing retention time and resulting in less effective treatment. Data in table 3.1-1 indicate that treatment for the non-flow through wetland is better in a wet year.

The status of knowledge concerning wetland hydrology has been summarized in recent reviews by Carter et al. (1979) and Gosselink and Turner (1978). Several other studies contain at least partial information on hydrology or water budgets for specific wetland wastewater treatment system sites. These include Bellaire, Michigan (Kadlec 1980), Houghton Lake, Michigan (Kadlec and Hammer 1980; Kadlec and Hammer 1982), Gainesville, Florida (Heimburg 1976), Drummond, Wisconsin (Kappel 1980), and Listowel, Ontario (Wile et al 1983).

3.1.2 Nutrient Cycling and Nutrient Removal in Wetlands

Municipal wastewater is characterized by relatively high levels of nutrients such as nitrates and phosphates (Table 3.1-2). Several recent studies have shown that natural wetlands are able to remove these substances effectively, resulting in improved water quality (Hammer and Kadlec 1982). To

Table 3.1-2. Characteristics of municipal wastewater from (USEPA 1973).

Constituent	Untreated Sewage (mg/l)	Typical Secondary-Treatment Effluent (mg/l)
Physical		
Total solids	700	425
Total suspended solids	200	25
Chemical		
Total dissolved solids	500	400
pH	7.0 ± 0.5	7.0 ± 0.5
BOD	200	25
COD	500	70
Total nitrogen	40	20
Nitrate-N	0	---
Ammonia-N	25	---
Total phosphorus	10	10
Chlorides	50	45
Sulfate	---	---
Alkalinity ($CaCO_3$)	100	---
Boron	---	1.0
Sodium	---	50
Potassium	---	14
Calcium	---	24
Magnesium	---	17
Sodium adsorption ratio	---	2.7
Biological		
Coliform organism (MPN/100 ml)	10^6	---

Source: U.S. Environmental Protection Agency. 1973. Waste treatment and reuse by land application. Prepared by C. E. Pound and R. W. Crites. Vol. 1. EPA-660/2-73-006a.

understand how wetlands accomplish this effect, the processes of nutrient recycling in natural wetlands must first be described. A review of the literature concerning this subject is presented in Section 3.1.2.1. The ability of wetlands to remove nutrients (either from natural sources or from wastewater) is then discussed in Section 3.1.2.2, based on a review of previous studies.

3.1.2.1 Nutrient Cycling in Natural Wetlands

Whigham and Bayley (1979) and Richardson et al (1978) provided reviews of studies concerning nutrient recycling processes in natural wetlands. Only a few quantitative studies have been made, however, in which the size of the nutrient pools or rates of internal transfer between ecosystem compartments were measured. Hammer and Kadlec (1982) presented a useful diagram of nutrient cycling in wetlands (Figure 3.1-11). These models summarize the major nutrient recycling processes that occur in wetlands, including inputs and outputs from the entire wetland system as well as internal recycling processes. Major nutrient inputs include atmospheric precipitation, surface water inflow, and groundwater inflow (although ombrotrophic bogs depend primarily on precipitation). Major nutrient outputs typically include surface water and groundwater. Internal cycling processes involve transfer of nutrients between various living and non-living ecosystem compartments. The net sum of these processes results in the observed losses of nutrients to surface water and groundwater outputs. The following sections provide a more detailed summary of the major nutrient cycling pathways in wetlands.

Nutrient Uptake by Wetland Vegetation

All vegetation requires some form of nutrients for internal metabolic processes, growth, and reproduction. Emergent wetland vegetation obtains nutrients from the soil by absorption through the root system. Wetland plants take up nutrients at rates which follow classic Michaelis-Menten kinetics (Nissen 1973). This pattern has been shown to be valid for a wide taxonomic range of plant species, although individual rates of uptake vary widely. At low nutrient concentrations, an active form of nutrient uptake process occurs (the so-called "high affinity system"). The active form of uptake requires an

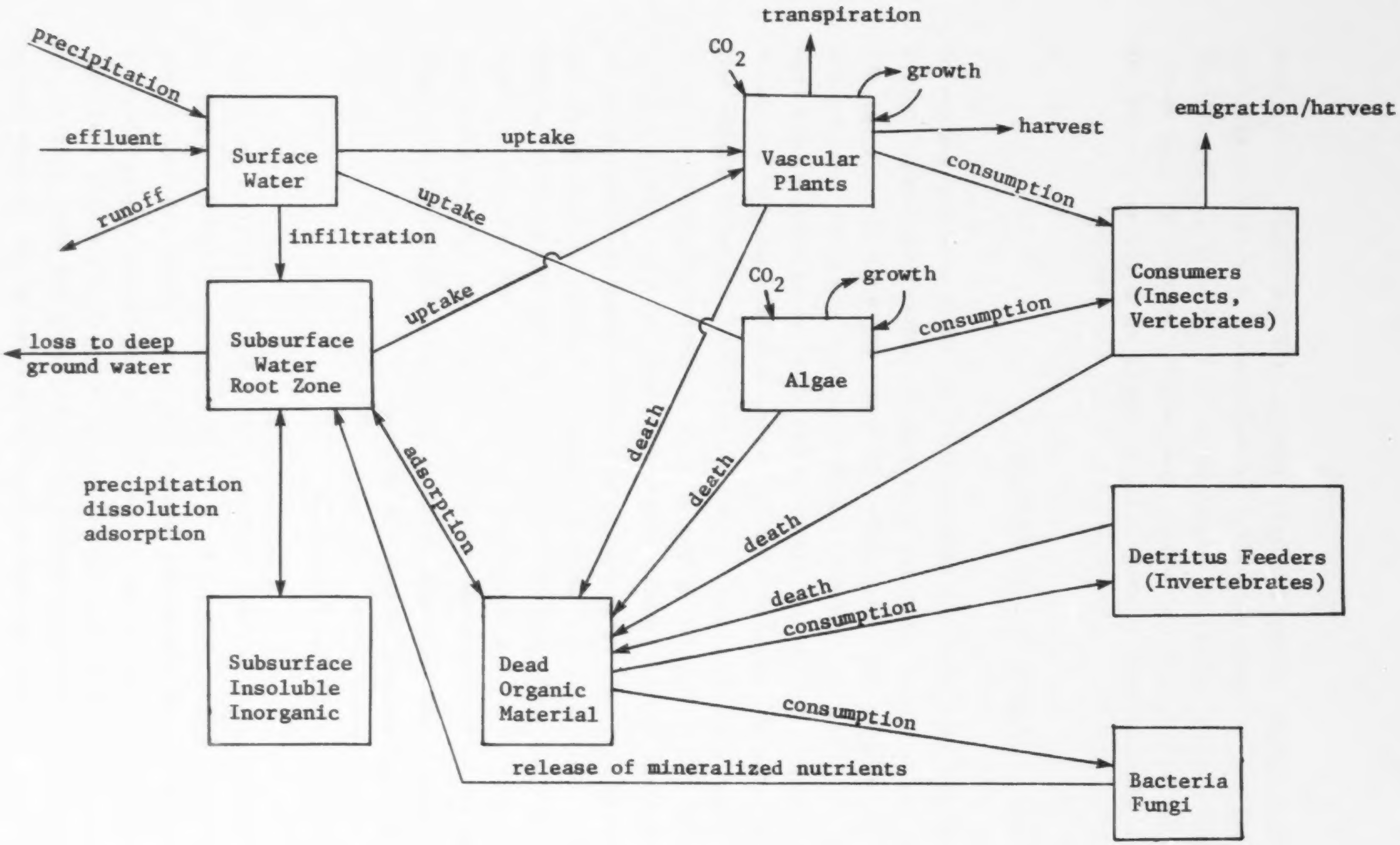
precipitation
effluent
runoff
Surface Water
infiltration
uptake
uptake
uptake
Subsurface Water Root Zone
loss to deep ground water
precipitation
dissolution
adsorption
Subsurface Insoluble Inorganic
adsorption
Dead Organic Material
CO_2
transpiration
growth
harvest
Vascular Plants
consumption
emigration/harvest
CO_2
growth
Algae
consumption
Consumers (Insects, Vertebrates)
death
death
death
death
consumption
Detritus Feeders (Invertebrates)
consumption
Bacteria Fungi
release of mineralized nutrients

Figure 3.1-11. Water and nutrient exchange between wetland components (from Hammer and Kadlec 1982).

expenditure of energy to transport nutrients into the root system. At higher nutrient concentrations, a form of passive diffusion predominates. The high affinity (active) system is the primary means of uptake in aquatic and wetland environments (Hutchinson 1975) but the more passive diffusion system might also be important in wastewater application systems with extremely high nutrient levels. Lahksman (1979) showed that uptake kinetics were different under high nutrient levels. Stanforth (1976) showed that nutrient uptake varied significantly in water milfoil (Myriophyllum), an aquatic macrophyte, with increasing levels of phosphorus. Stanforth (1976) also showed that nutrient uptake decreased as flow rate (currents) increased, a factor of importance in wetland-wastewater application problems. Trace materials may also reduce nutrient uptake rates by affecting enzyme active transport systems (Stanforth 1976).

Nutrient availability may limit the growth of many natural wetland plants (Prentki et al. 1978). If nutrients are available in amounts which exceed the plants metabolic requirements, however, the plant typically continues to absorb nutrients, which are then stored. This so-called "luxury" uptake has been demonstrated for many aquatic and emergent plants (Gerloff 1975). In addition, every plant has a "critical" nutrient concentration in the environment below which growth is limited (Gerloff and Krombholz 1966). In the case of a wetland receiving treated wastewater, luxury uptake would be expected for nutrients such as nitrogen and phosphorus. Similarly, addition of wastewater to a system naturally limited by a particular nutrient (for example, peat bogs, which are usually low in nitrogen) would be expected to cause a shift in species composition towards those forms more able to utilize excess amounts of nitrogen.

Nutrient uptake rates also vary with the phenotypic (growth) stage of the plant during the course of the year. Uptake is generally greatest during the most rapid growth phase, which in turn varies with the time of year, depending on the species of plant. Also, "de novo" uptake from plant rhizomes, in which nutrients pass from the rhizome to the leaf, has been demonstrated. In cattails, two-thirds of the total P uptake, for example, was accounted for by uptake from the rhizomes (Prentki et al. 1972). Shoots and roots also differ in their nutrient uptake rates (Smith 1978 in Heliotis 1982). Finally, uptake rates vary widely among species, even though overall kinetics are similar (Dykyjova 1978; Klopatek 1975).

Periphyton (attached epiphytic and epilithic algae) may account for an equal or greater amount of primary production as compared with submerged and emergent macrophytes in some wetlands (Jones 1980; Kowalczewski 1975; Correl et al. 1975). As a result, periphyton play an important role in nutrient recycling in these systems. For example, periphyton have been shown to account for a significant amount of phosphorus removal in some wetlands. Periphyton of a *Typha*-dominated tidal marsh were found to be the major pathway of phosphorus removal (Correl et al. 1975). Phosphorus uptake by periphyton in an everglades marsh was shown to equal uptake rates by cattails (Davis and Harris 1978). The role of periphyton in nutrient uptake should therefore be carefully considered in future studies of nutrient cycling in wetlands and wetland wastewater application. It would be expected that periphyton production would be stimulated by added wastewater, and that the cycling of nutrients would be significantly affected as a result. It is not known if excessive growths of periphyton would be produced or if this would pose a possible water quality problem due to increased BOD loading. Only further study will enable this question to be addressed.

Nutrient Levels in Wetland Plants

Wetland plants store nutrients in their tissues, thus representing a pool of these materials at a specified point in time. The standing stock of nutrients varies throughout the year, and for specified time is equal to the product of biomass (grams dry weight/m^2) times the tissue nutrient concentration (% of dry weight). Klopatek (1975) described the following four phases of the seasonal nutrient cycle of a wetland plant:

- Phase 1: Beginning of the growing season, when the plant tissues contain the highest nutrient concentration;
- Phase 2: Short period of peak nutrient uptake, usually preceding peak biomass accumulation;

- Phase 3: Peak of nutrient standing stock, which may or may not coincide with peak biomass; and
- Phase 4: Decline and leveling off of nutrient concentration.

Typical levels of nutrients in wetland plants are shown in Table 3.1-3. This provides some indication of the range to be expected in future studies, and also shows that data on both biomass and tissue nutrient levels must be obtained to accurately determine nutrient pools.

Role of Animals in Nutrient Cycling

Animals influence nutrient cycling in wetlands by producing particulate matter, maintaining sediment stability, excreting ammonia, and grazing (Valiela and Teal 1978). Second trophic level animals in wetlands include direct herbivores (direct grazers on vegetation) and detritivores (consumers of dead plant material). Direct herbivores generally consume a relatively low percentage of the total biomass in wetlands (Moore and Bellamy 1974; Teal 1962; Pelikan 1978). Detritovores consume significant portions of the biomass produced in salt marshes (Teal 1962), but only a small percentage of submerged macrophytes in a lake were shown to be consumed by detritovores (Carignan and Kolff 1980). In general, detritovores such as amphipods and other invertebrates are responsible for reducing the particle size of leafy dead plant material, thereby increasing the surface -to-volume ratio of the material and increasing the rate of decomposition (Hynes 1970). Rate of decomposition is increased by active build-up of microbial populations on the detritus as it is shredded into smaller particles, which in turn increases the rate of nutrient cycling.

Few data are available on the transfer of nutrients to higher trophic levels. These pathways would involve carnivorous and insectivorous animals. Mammals in general may be an important factor affecting the rate of internal nutrient cycling in wetlands.

Table 3.1-3 Nutrient standing stocks in some wetland macrophytes.

			Nitrogen		Phosphorus		
		Biomass	Tissue Concentration	Peak Standing Stock	Tissue Concentration	Peak Standing Stock	
Species	Study Period	g/m^2	% dry weight	g/m^2	% dry weight	g/m^2	Study Site/Reference
Phragmites communis	May-Oct.	1,025-2,731	1.00-2.77	41	0.17-0.48 (0.26)	53	Opatovicky fishpond (Kvet 1975; Dykyjova 1978)
Typha angustifolia	May-Oct.	430-2,600	0.8-2.9	32.7	0.15-0.49	6.4	Everglades conservation (Davis and Harris 1978)
	June-May	927-2,350			0.05-0.26	2.39	
Typha latifolia	May-Oct.	2,456	0.44-2.45	12.00	0.17-0.63	2.25	Theresa Marsh, Wisconsin (Klopatek 1975)
	May-July	190-680	0.51-2.40	5.35	0.09-0.31	0.77	Par Pond, South Carolina (Boyd 1970)
Acorus calamus	May-July	117-792	1.26-2.92	21.3	0.2-0.35	3.3	Opatovicky fishpond (47,94) (Kvet 1975; Dykyjova 1978)
Scripus lacustris	May-Oct.	170-1,650	1.03-1.77	52.9	0.23-0.34	11.1	Opatovicky fishpond, Theresa Marsh (Kvet 1975; Klopatck 1975)
Scripus americanus	May-July	90-150	0.83-2.72	1.66	0.13-0.30	0.23	Par Pond, South Carolina (Boyd 1970)
Scripus fluviatilis	May-Sept.	1,533	1.10-3.25	15.4	0.08-0.75	3.3	Theresa Marsh, Wisconsin (Klopatek 1975)
Carex lacustris	May-Sept.	1,186	0.60-1.70	7.7	0.16-0.31	1.95	Theresa Marsh, Wisconsin (Klopatek 1975)
Taxodium	July-June	29,000	0.24-1.43	97.0	0.009-0.1	4.35	Okefenokee swamp (Schlesinger 1978)

Cycling of Nutrients During Decomposition

Figures 3.1-12 and 3.1-13 summarize general pathways of plant and animal decomposition in wetlands, although these processes are in fact not well understood (Gallagher 1978). Organic (plant or animal) matter may follow two different pathways of decomposition. Under low-oxygen, water-saturated conditions, decomposition is slow and follows a series of fermentation processes (Figure 3.1-12). This leads to a gradual accumulation of organic sediment (peat). This process occurs when the decomposition rate is consistently less than the rate of litter accumulation. Nitrogen is released during anaerobic decomposition as nitrogen (N_2), nitrogen oxide (N_2O), or nitrous oxide (NO); whereas phosphorus, sulfide ($S^=$) and hydrogen sulfide (H_2S) are released during sulfate reduction (Figure 3.1-13). The alternate pathway occurs under oxygen-rich situations. Under these conditions aerobic respiratation predominates, and fungi and bacteria rapidly break down the plant material, resulting in release of stored nutrients (Figures 3.1-12 and 3.1-13). Other metabolic products of aerobic respiration primarily include CO_2 and H_2O.

The standing litter compartment includes plant material that has died but has not yet fallen onto the surface of the wetland, where it will undergo more rapid decomposition as it comes in contact with water. Shoot death produces the standing litter compartment. However, shoot death is variable and occurs throughout the year, depending on the species of plant. Microbial decomposition of the standing litter compartment is of minor importance in nutrient cycling. Instead, winter winds and rains plus animal disturbance are the primary factors affecting decomposition. Nutrient losses are incurred mainly by leaching, translocation, and fragmentation (Davis and van der Valk 1978b).

The fallen litter compartment includes dead plant material that is in immediate contact with the soil surface. Oxygen levels in the soil generally determine decomposition reactions that occur in the fallen litter compartment. Water-logged soils rich in organics rapidly form a thin layer of oxidized material that decomposes plant and animal detritus by aerobic processes (Figure 3.1-13). Deeper layers undergo anaerobic decomposition (Figure 3.1-13).

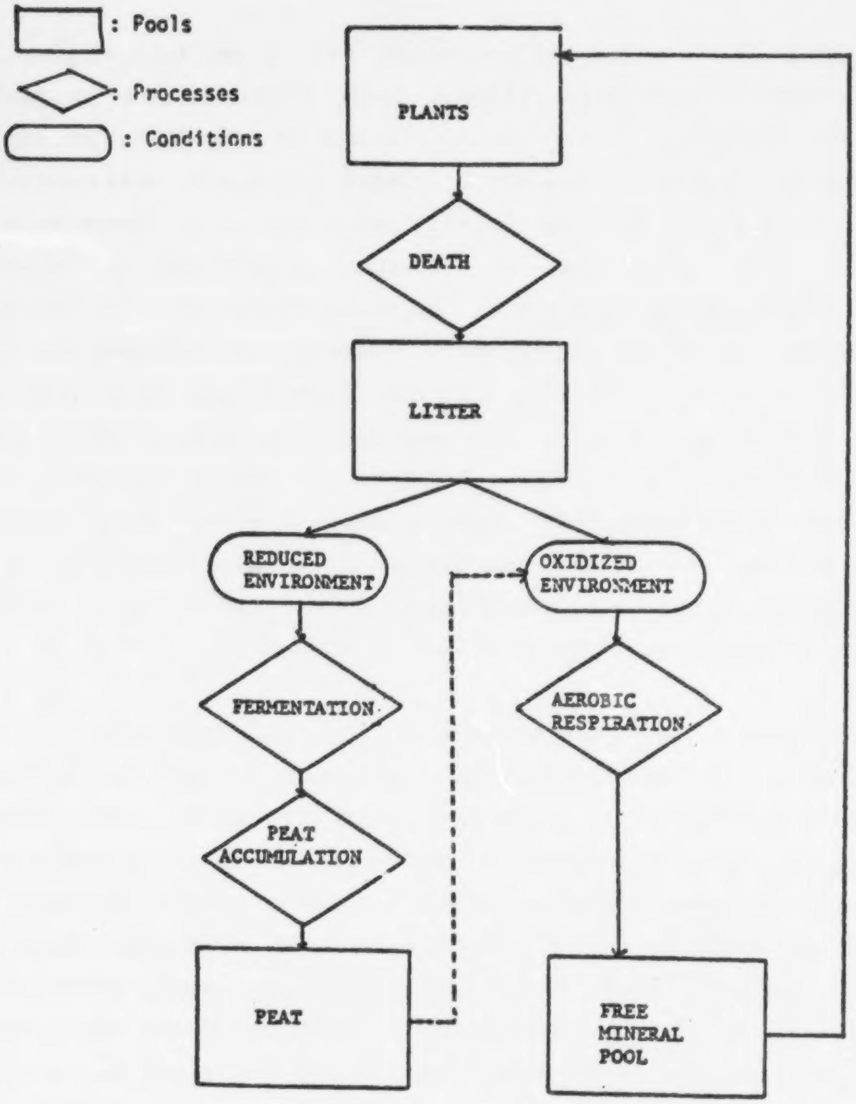
: Pools
: Processes
: Conditions
PLANTS
DEATH
LITTER
REDUCED ENVIRONMENT
OXIDIZED ENVIRONMENT
FERMENTATION
AEROBIC RESPIRATION
PEAT ACCUMULATION
PEAT
FREE MINERAL POOL

Figure 3.1-12. Nutrient pathways during decomposition (from Heliotis 1982).

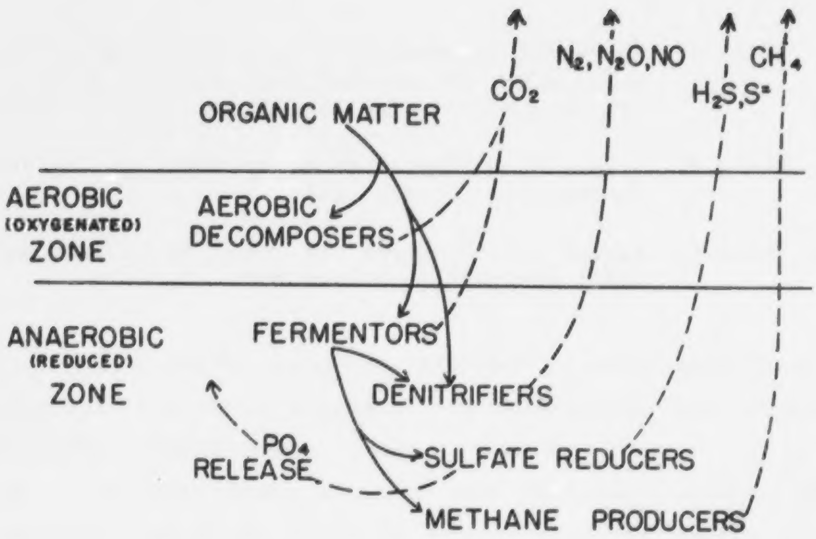
CO₂
N₂, N₂O, NO
H₂S, S⁼
CH₄
ORGANIC MATTER
AEROBIC (OXYGENATED) ZONE
AEROBIC DECOMPOSERS
ANAEROBIC (REDUCED) ZONE
FERMENTORS
DENITRIFIERS
PO₄ RELEASE
SULFATE REDUCERS
METHANE PRODUCERS

Figure 3.1-13. Major microbial decomposition and recycling pathways in wetland sediments (from E. P. Odum 1978).

Decomposition in the fallen litter compartment is initiated by shredding organisms (e.g., amphipods) or by mechanical action (Axelrod, et al. 1976). The sequence of events during decomposition is as follows:

- Phase A: increased production of dissolved organic material, which is metabolized rapidly; maximum DOM production occurring soon after initial leaching;
- Phase B: a period of decreased decay rates due to various interacting factors; and
- Phase C: asymptotic decrease in rate of decomposition, which eventually reaches zero.

The actual decay rate of detrital material varies widely. Decay rates are affected by many factors,and are largely a function of the composition of the plant material (i.e., percent labile, versus percent refractory components) and the existing physical and chemical conditions (i.e., acid bog versus alkaline marsh; northern versus southern location, hydrologic conditions, etc.).

Nutrient Dynamics During Decomposition

During decomposition, nutrients are exchanged due to internal translocation (removal of nutrients from dying leaves and transfer to rhizomes), leaching, and nutrient accumulation during particle breakdown (microbial buildup on detritus and accumulation of phosphorus and nitrogen by microbes during conversion of plant cellulose to protein, for example). However, little is known concerning the details and relative importance of these processes. The following is a summary of nutrient dynamics during decomposition:

- In some species, such as Typha latifolia, a large amount of phosphorus (23%) is translocated back to the rhizomes prior to leaf death;
- Leaching rates vary with type of vegetation, its physical condition, respiration rates, and oxygen levels (Chamie and Richardson 1978). Increasing submergence, for example, may increase leaching (Davis and van der Valk 1978c);
- Microbial uptake of P and N may be a significant portion of total macrophyte uptake (Davis and Harris 1978);

- Faster-decomposing plants are composed of lower amounts of resistant lignins and lower C:N ratios (Davis and van der Valk 1978; Godshalk and Wetzel 1978); low levels of lignin enhance microbial populations and speed up decay rates and nutrient cycling;
- Species more resistant to decomposition act as buffers by releasing nutrients more slowly over time; and
- Plant morphology affects nutrient uptake patterns and rates, in that dissimilar species may have similar patterns of breakdown.

The above factors, plus the full range of physical and chemical conditions, affect the role of litter as a nutrient sink in wetlands. As a general rule, as litter builds up in older wetlands, it becomes more effective as a nutrient sink due to increased available surface area and microbial activity. (various authors _in_ Heliotis 1982).

Incorporation of Nutrients by Sediments

Nutrients contained in plant tissues may be incorporated into the sediments in several ways. A major pathway is via the slow process of peat soil formation. Peat is as a general soil type resulting from the gradual accumulation of slowly decaying plants and other organic material over time, and is described more fully below. Peat soil formation rates are affected by numerous factors, including hydrologic regime, nutrient levels, climate, and basin morphometry (Friedman et al. 1979). The type of peat soil formed depends on the species of plants, the climate at the time the plants were growing, and the types of decomposing microorganisms (Moore and Bellamy 1974). Nutrient retention ability varies between different peat types, and is therefore a factor affecting performance of wetlands receiving applied wastewater.

Adsorption to suspended sediment particles and subsequent settling is the primary mechanism for removal of colloids, nitrogen, phosphorus, trace metals, and organics from the water column in wetlands (Tchobanoglous et al. 1979). Removal of suspended solids and attached substances in wetlands is caused primarily by lowered water velocity as water flows through standing vegetation (Boto and Patrick 1978).

Chemical precipitation reactions also produce a transfer of chemical compounds from the water column to the sediments (Stuman and Morgan 1981). Precipitation is the major mechanism for removal of phosphorus and trace metals (in general, phosphate precipitates above $pH = 8.0$ assuming suitable cations such as iron or calcium are present). Periphyton are also a major removal mechanism for phosphate in some wetlands (Correl et al. 1975; Davis and Harris 1978). Adsorption reactions are an additional important mechanism for nutrient removal and are discussed in the following section.

Wetland Substrates

A variety of wetland substrates may form. Figure 3.1-14 summarizes the major types of wetland substrates that can form in response to various factors. Wetland soils may be composed of a mixture of minerals (sand, silt, clay), organics (peat, mulch), or both (Lee 1977; Brown et al. 1979). Under conditions of higher rates of alluvial deposition, low biogenic accumulation, and high water turnover (flux/storage), inorganic sediments predominate. Under low current conditions where biogenic accumulation rates and alluvial deposition rates are low, organic peat soils develop (Figure 3.1-15).

Wetland soils have several features, that are characteristic of all submerged soils; these are as follows (Ponnaperuma 1972):

- The absence of molecular oxygen and reduced soil conditions in deeper layers;
- A thin, oxidized mud-water layer; and
- The presence of marsh plants (usually).

The oxidized soil-water interface is of particular importance to nutrient cycling in wetlands. This layer absorbs and retains phosphate, silica, and trace metals from the water column and the deeper anaerobic layers of the sediment). It also causes nitrification (conversion of nitrogen to nitrate) which reduces the amount of nitrogen in the water column (Keeney 1972).

The anaerobic zone is in a reduced state, and is characterized by high levels of ammonia ($NH+_4$), hydrogen sulfide (H_2S), reduced manganese and iron,

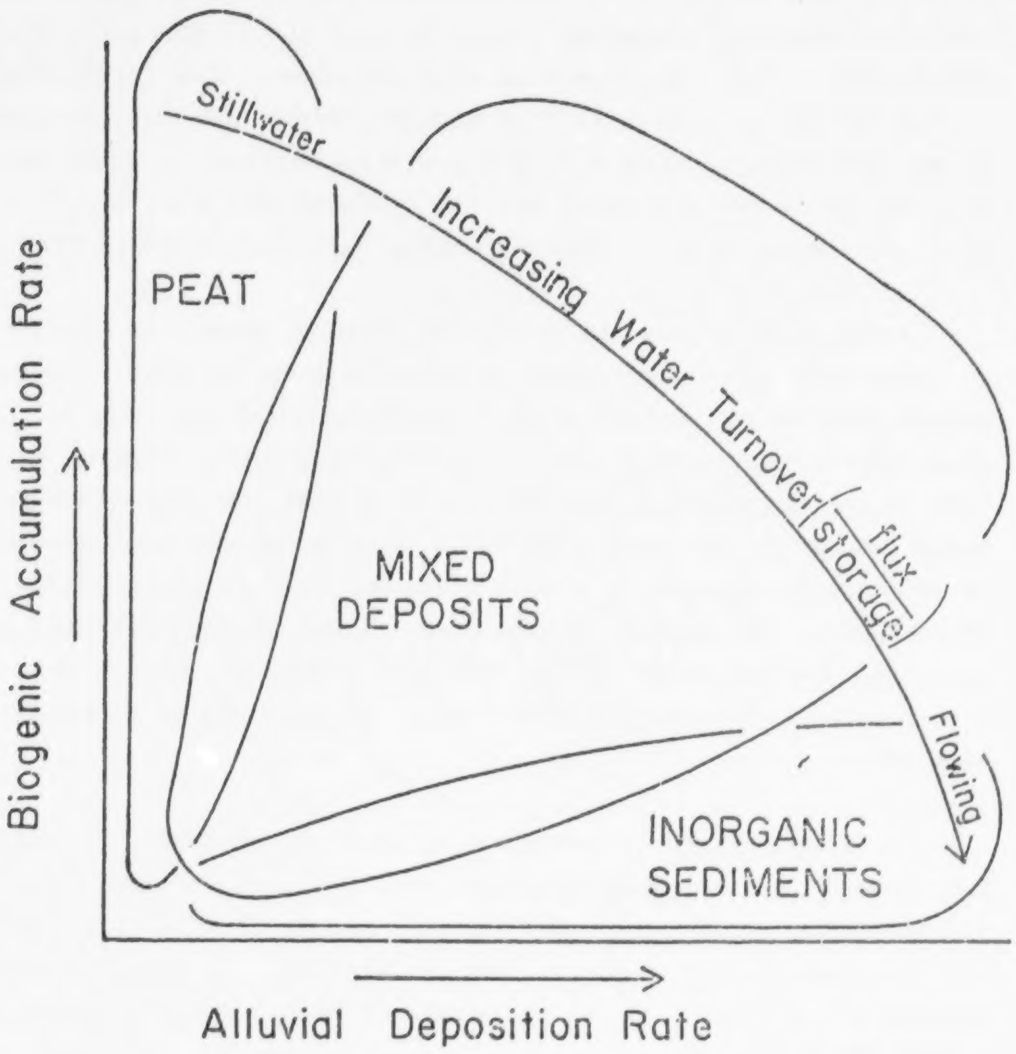
Stillwater
Increasing Water Turnover
flux
storage
Flowing
PEAT
MIXED DEPOSITS
INORGANIC SEDIMENTS
Biogenic Accumulation Rate
Alluvial Deposition Rate

Figure 3.1-14. Factors influencing wetland soil formation (from Brown et al. 1979).

and methane (CH_4^+). This zone acts as a release for phosphate when the surrounding water is low in soluble phosphate, but will absorb phosphate from solutions high in this ion. This is caused mainly by the process of adsorption to ferrous and manganese colloidal gels (Li et al. 1972; Patrick and Khalid 1974). The reduced zone is also the primary site for denitrification (transformation of nitrate to free nitrogen (Figure 3.1-13). In general, low pH and low redox potentials (eH) favor solubilization of trace metals, but this may be countered by metal sulfide precipitation, adsorption to colloidal gels, and complexing with organics (various authors in Heliotis 1982).

Cation exchange capacity is also an important measure of a soil's ability to remove nutrients. The process of cation exchange involves a replacement of charged ions on the surface of microscopic colloidal particles by other ions which have a higher charge (e.g., a greater electronic affinity for the surface of the charged soil particles). In general, the higher the cation exchange capacity, the more effective a soil is in removing nutrients. The cation exchange capacity of a soil increases with increasing mineral content (Sjors 1961). In general, soil nutrient removal capacity decreases gradually over time due to saturation of available adsorption sites. Thereafter, a steady state is attained in which removal is primarily by filtration (Mechenich 1980).

The ultimate fate of nutrients in soils may include: (1) leaching out and removal; (2) remaining attached and incorporation into the sediment; (3) release by cation exchange, microbial action, fire, or via plant uptake; and (4) remaining attached and lost by erosion. In managing wetlands for nutrient assimilation, the objective should be to achieve permanent incorporation into the sediments.

3.1.2.2. Ability of Natural Wetlands to Remove Nutrients

This section summarizes the literature concerning the ability of wetlands to remove nutrients. Although the discussion focuses primarily on wetlands receiving applied municipal wastewater, examples of the ability of natural wetlands to remove nutrients as well as examples of wetlands to treat stormwater runoff are also included. These also provide useful examples which are applicable to the problem of using wetlands as a means of advanced treatment or as a point of wastewater discharge.

The ability of natural wetlands to remove nutrients varies widely. Various investigators have attempted to correlate nutrient removal with numerous factors, but few good correlations have been established that apply to all wetlands. This is due primarily to the wide variety of wetland types and the large number of factors affecting nutrient retention. However, several trends can be recognized that illustrate the possible ways in which nutrient removal is accomplished among different wetland types, and the factors that are important in controlling nutrient removal.

Loading Studies

Nichols (1980a,b,c) reported that natural wetlands receiving wastewater or fertilizers varied widely in their N and P removal efficiency. Good phosphorus removal efficiencies were indicated at low loading rates (less than 5 grams $P/m^2/year$) for all wetlands. However, efficiencies of P removal rapidly dropped at higher loading rates (above 10 grams $P/m^2/year$). A similar pattern was noted for N removal (but at different loading rates).

Using the average per capita loading estimates of 2.2 g phosphorus and 10.8 g nitrogen per day in domestic wastewater (Vollenweider 1968 in Nichols 1980a), Nichols converted the P and N loading rates to numbers of people to indicate the efficiencies of removal that might occur if the wastewater produced by each population were applied to a 1-hectare (ha) wetland. Based on the revised estimates, approximately 1 ha of wetland would be required for every 60 people to attain 50% removal of N and P. The same amount of wetland could provide 75% removal for a population of 20 persons. Nichols noted that the estimated loading rate to nutrient removal relationships are generalized, and that efficiencies of removal would vary according to the particular conditions at each site. In general, however, high removal efficiencies are achieved when the number of people served per ha is small. However, since little is known concerning the long-term ability of wetlands to remove nutrients (removal efficiency may decline greatly over long periods of time), results of short-term studies can be misleading.

Although removal of nitrogen appears to be largely a function of microbial activity and could continue as long as healthy microbial populations are maintained, the length of time during which a particular wetland can effectively remove phosphorus from wastewater is unknown. Presumably, wetland soils with higher levels of aluminum, iron, calcium, and clay (the primary substances that bind phosphorus) would function in this capacity over longer periods of time than wetlands with lower levels of these substances. If the phosphorus adsorption capacity of a wetland soil becomes saturated, the soil may release some of phosphorus, particularly if the concentration in the overlying water is reduced, as happened at Dundas, Ontario (McLarty n.d. in Nichols n.d.). The phosphorus and nitrogen removal efficiency of a specific wetland may also be less during periods of the year when no plant growth occurs.

Hammer and Kadlec (1982), Kadlec (1982) and Kelly and Harwell (1983) summarized information from the literature concerning nutrient retention in wetlands as a function of age, loading, and other factors. Hammer and Kadlec (1982) summarized the information concerning major factors affecting the ability of a wetland to treat wastewater (Table 3.6-1, Section 3.6), and related nutrient removal rates to loading rates (Figures 3.1-15 and 3.1-16 and Table 3.1-4). Removal rates generally correlated with loading rates. However, older systems seem to be displaced towards poorer removal efficiencies.

Other Studies on Nutrient Removal

Kelly and Harwell (1983) showed that added inputs of nitrogen to terrestrial and wetland systems result in a general increase in nitrogen output (Figure 3.1-17). The nitrogen output is generally equal to about 43% of the input for all ecosystems studied (including wetlands) (Figure 3.1-17). However, there was only a poor relationship at low loading rates. In contrast, phosphorus input-output relationships were not linear (Figure 3.1-18) in that terrestrial and wetland ecosystems exhibited good phosphorus removal even at high inputs. Phosphorus input was thus not strictly proportional to output. Wetlands varied one order of magnitude with respect to phosphorus retention ability (Figure 3.1-19).

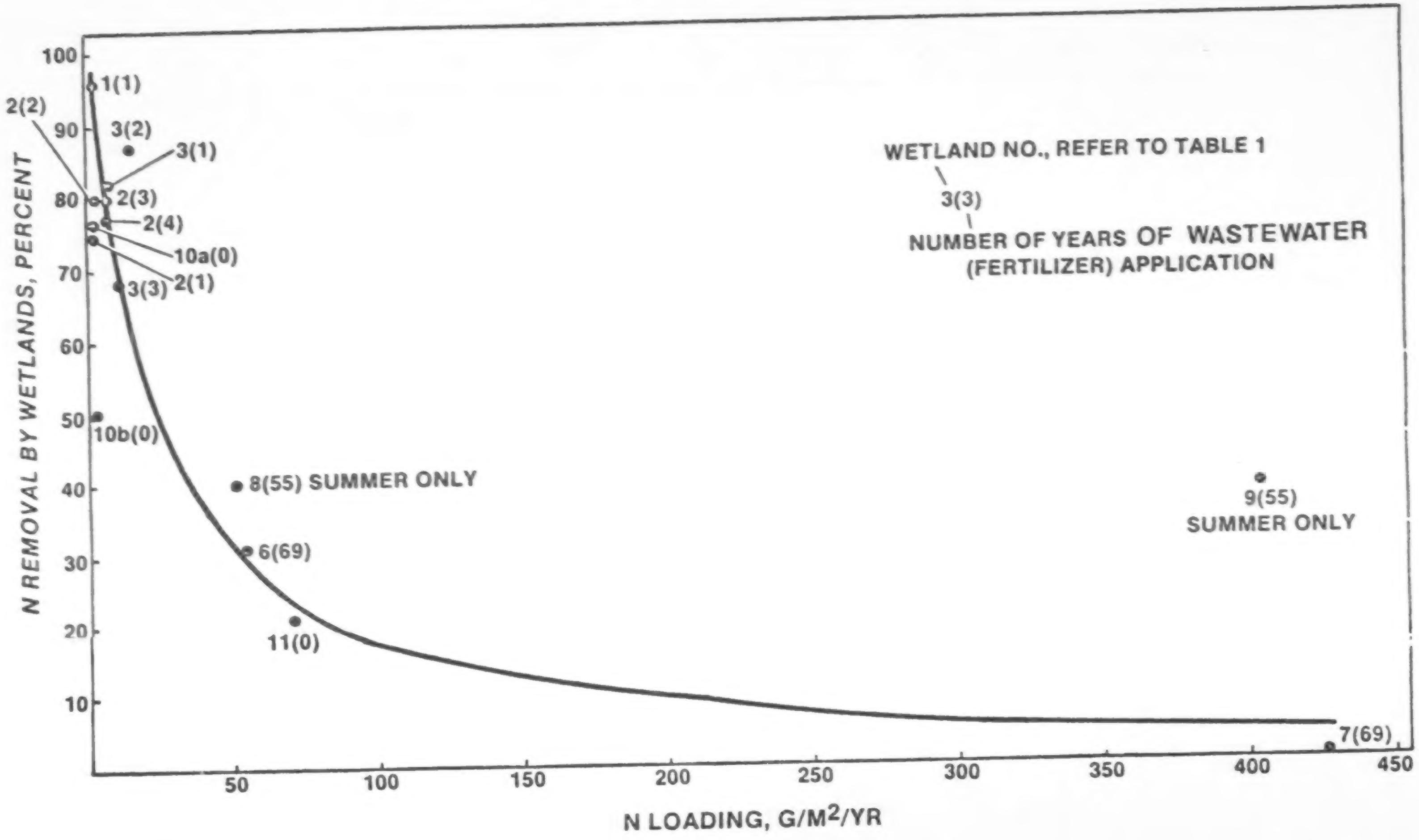

Figure 3.1-15. Effect of phosphorus loading on removal rate (from Hammer and Kadlec 1982). Numbered sources of information are listed in Table 3.1-4.

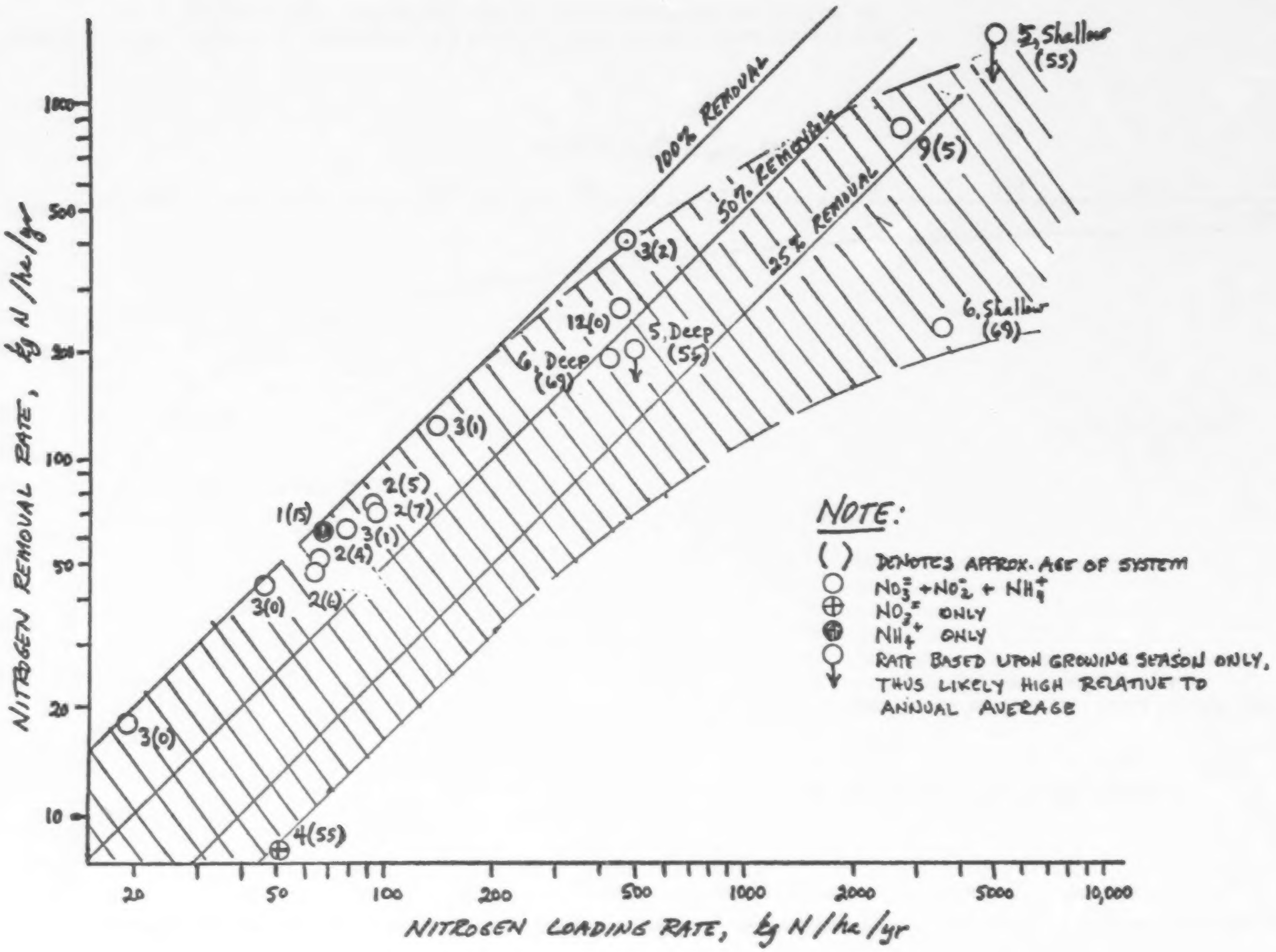

Figure 3.1-16. Effect of nitrogen loading on removal rate (from Hammer and Kadlec 1982). Numbered sources of information are listed in Table 3.1-4.

Table 3.1-4 Operating systems reporting rate data for Figures 3.1-15 and 3.1-16 (from Hammer and Kadlec 1982).

No.	Site	Data Sources
1	Hay River	Hartland-Rowe and Wright (1975)
2	Bellaire	Kadlec (1979), (1980), (1981); Kadlec and Tilton (1978)
3	Houghton Lake	Kadlec and Hammer (1980), (1981b); Kadlec (1979); Kadlec et al. (1979)
4	Brillion	Spangler et al. (1976), (1977)
5	Clermont	Zoltek et al. (1979)
6	Great Meadows	Yonika et al (1979)
7	Wildwood	Boyt et al (1977)
8	Waldo	Nessel and Bayley (1980)
9	Mt. View	Demgen (1981)
10	Cootes Paradise	Semkin et al. (1976)
11	Seymour	Spangler et al. (1977)
12	EBC System	Nute and Nute (1979)

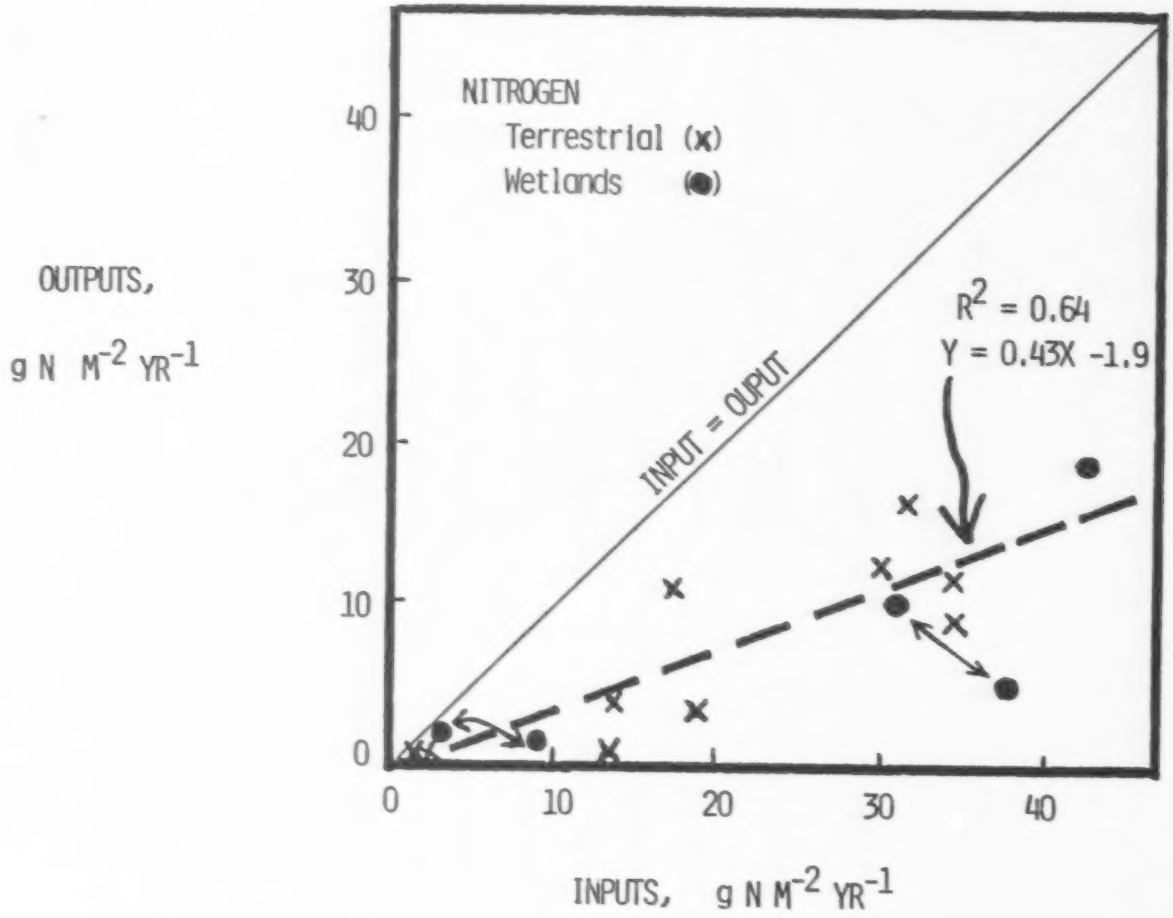

Figure 3.1-17. Relationship between nitrogen outputs and nitrogen inputs derived from previous studies of wetland and terrestrial ecosystems (from Kelly and Harwell 1983).

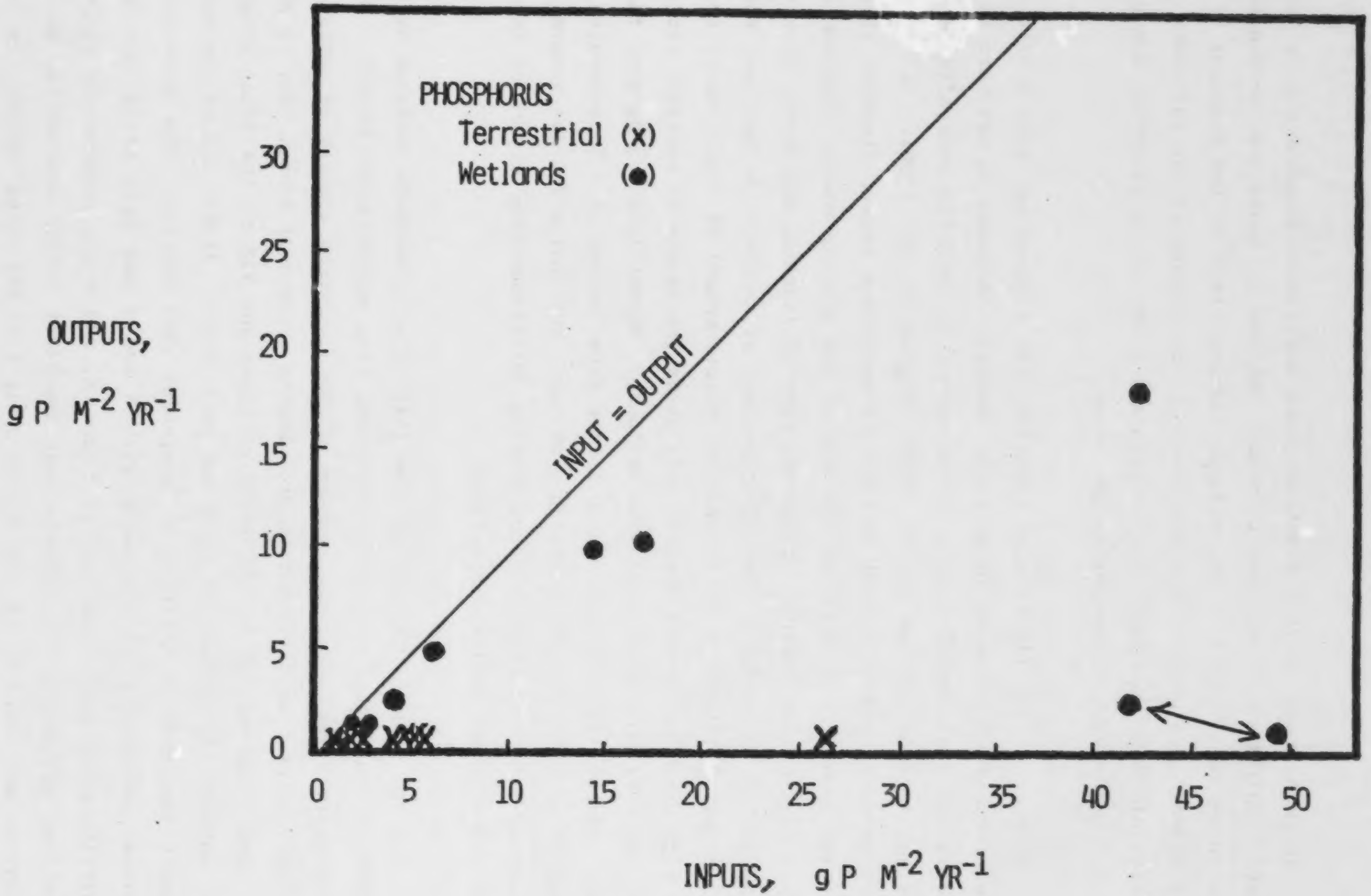

Figure 3.1-18. Relationship between phosphorus outputs and phosphorus inputs derived from previous studies of wetland and terrestrial ecosytems (from Kelly and Harwell 1983)

Whigham et al. (1980) discussed some additional factors that affect the relative abilities of wetlands to remove nutrients. Wastewater renovation was said to be most effective in wetlands characterized by the presence of thick peat organic sediments. Nutrient removal (no mention of the influence of ash content was made) was said to be determined primarily by microbial degradation and physical-chemical adsorption processes.

Whigham et al. (1980) also reported that climate may play a role in the effectiveness of wetlands in nutrient removal. Wetlands in northern climates where winters are particularly severe appear to function less efficiently in nutrient removal (Fetter et al. 1978; Whigham et al. 1980). In freshwater tidal wetlands characterized by high decomposition rates, flushing of nutrients may occur in a pulse at the end of the growing season (Whigham et al. 1980). Hydrologic factors, including rate of flushing and depth, also may be important in determining the effectiveness of wetlands in nutrient removal. High-energy, freshwater tidal marshes characterized by rapid water movement and high tidal amplitudes exhibit relatively low levels of nutrient removal as compared with freshwater non-tidal wetlands. Blumer (1980) suggested that the lowest removal efficiencies would result from designs that incorporated rapid movement of water directly through a wetland, and that effective removal would be accomplished by designs incorporating interconnecting series of intermittent channels and pool wetland types.

Day and Kemp (1983) studied the ability of a southern forested swamp (in Louisiana) to retain nutrients resulting from agricultural runoff. The results apply directly to the problem of the long-term ability of wetland ecosystems to treat applied wastewater. During a two-year study, they found that the swamp removed 21% of the total nitrogen and 41% of the total phosphorus that entered the system during a two year study. Almost all of the nutrient removal was due to settling of suspended particulates. The potential for eventual saturation of the swamp with N and P was said to be low because denitrification would continue to remove N, and P was permanently removed by subsiding sediments. The single most important factor controlling phosphate retention was found to be the oxygen content of the water column. An inverse relationship was found between phosphate levels and dissolved oxygen levels (Figure 3.1-19). Despite effective removal, the swamp still exported signifi-

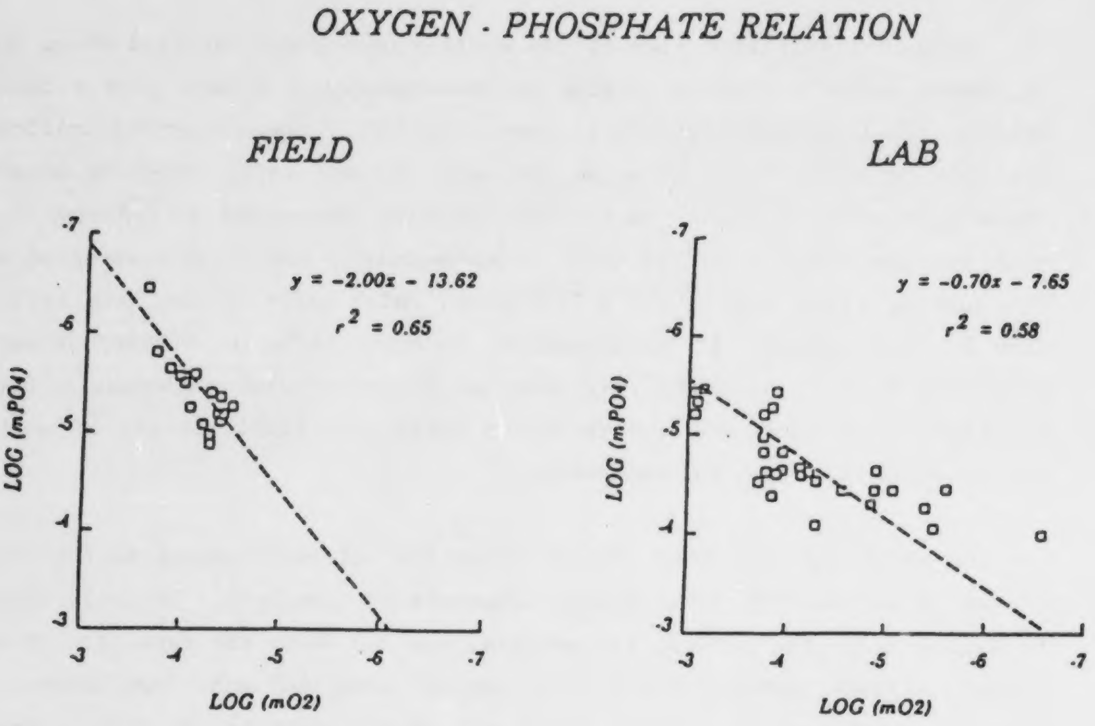

Figure 3.1-19. Relationship between phosphate levels in the water column and dissolved oxygen levels in a southern forested wetland (from Day and Kemp 1983).

cant amounts of these materials. The primary mode of action of the swamp in nutrient removal was thus as a buffer acting to prevent large pulses of nutrient loss over time.

Brinson (1983) also studied the ability of a North Carolina swamp forest to remove added nutrients. Using an experimental treatment plot technique, Brinson (1983) showed that nitrate was effectively removed by denitrification and that ammonium accumulated on the soil surface until dry-down occurred, allowing denitrification. Filterable reactive phosphorus accumulated in the soil but the capacity of the soil to accumulate P was rapidly exceeded under the loading rates used (0.19 g P/m^2/week, which exceeded the rate typically used for wastewater). It was suggested, in contrast to the studies by Day and Kemp (1983) that phosphorus may have no long-term sink (subsidence was not analyzed by Brinson) and may therefore ultimately limit the use of wetlands for treatment of municipal wastewater.

An additional potential factor affecting nutrient removal is the trophic status of surrounding water bodies connected to a wetland. Wetlands adjacent to highly eutrophic waters, for example, may not have the capacity for additional nutrient uptake (i.e., they may be saturated with nutrients). For example, Whigham et al. (1980) found only minor increases in primary production due to applied wastewater in a tidal freshwater marsh, presumably because of high ambient nutrient levels which existed prior to the application of wastewater to the wetland. An additional related factor here would include the possible effects of non-point runoff on the nutrient retention ability of a specific wetland. If a wetland were overloaded or saturated with phosphorus and nitrogen from agricultural areas, for example, it would not be feasible to apply wastewater to such a site.

Summary of Literature Concerning Nutrient Removal

A summary of previously published information concerning the treatment effectiveness of various wetlands receiving wastewater is presented in Table 3.1-5. Two of the wetland categories in Table 3.1-5 northern peatlands and nontidal freshwater wetlands, occur in USEPA Region V, and are briefly discussed here.

Table 3.1-5. Performance and operating mechanisms of wetlands receiving wastewater (from Heliotis 1982).

Type	Location	Loading people/acre	Substrate	Nutrient	% Removal	Macrophyte Uptake	Algal/ Litter Uptake	Substrate Adsorption	Nitrif/ Denitr	Precipitation	Tidal Transport	Reference
NORTHERN PEATLANDS												
Ombrotrophic bog	Wisconsin	12	0	NH_4-N	97	+	+		+			Mechenich 1980
				NO_2-NO_3-N	100	+	+		++			
				TP	78	+	+	++				
Sedge-shrub fen	Michigan	3	0	NH_4-N	71	+	+	+	+			Kadlec 1978; Kadlec and Kadlec 1978; Richardson et al. 1978 Richardson et al. 1976; Tilton 1977; Tilton and Kadlec 1979
				NO_2-NO_3-N	99	+	+		++			
				TDP	95	+	+	++				
Forest-shrub fen	Michigan	11	0	TDN	80	+	+		++			Kadlec and Tilton 1978; Tilton and Kadlec 1979; Gaudet 1976
				TDP	88	+	+	++				
NONTIDAL FRESHWATER MARSHES												
Cattail marsh	Wisconsin	7	0	NO_3-N	51*	+			+			Fetter et al. 1978
				TP	32	+	+	+				
Lacustrine *Glyceria* marsh	Ontario			TN	38	+			+			Mudroch and Capobianco 1979
				TP	24	++	++			++		
Deepwater marsh (½ meter depth)	Florida	40	0	TP*	97	+		+				Dolan et al. 1978
Lacustrine deepwater marsh	Wisconsin		0	DP	14			++				Perry 1981
				PP	82					++		
Lacustrine Phragmites marsh	Hungary			TN	95*	+	+		+			Sloey et al. 1978
TIDAL FRESHWATER MARSHES												
Deepwater Phragmites marsh	Louisiana		0	TN	51	+			++		+	
				TP	53	+	++	++				Sloey et al. 1978, Turner et al. 1976
Complex marsh	New Jersey	80	I	TN	40	+	++		++			Simpson and Whigham 1978; Whigham and Simpson 1976a Whigham and Simpson 1976b; Whigham and Simpson 1978 Whigham et al. 1980
				TP	0	+	++					
TIDAL SALT MARSHES												
Brackish marsh	Chesapeake Bay		O/I	TN	0	+			+		++	
				TP	1.5g/m²/yr	+	+				++	Bender and Correl 1974
Salt marsh	Georgia	sludge	O/I	TN	50	++					++	
Salt marsh	Massachusetts	sludge	O/I	TN	85	+	+					Chalmers et al. 1976
					88	+	+				++	Odum and Smith 1980
Salt marsh	Pennsylvania			TN	13.1 lb	+	+				+	Grant and Patrick 1970
				TP	6.4						++	
EVERGLADES												
Sawgrass freshwater marsh	Florida		0	TP	95	+	++					Steward and Ornes 1975
SOUTHERN SWAMPS												
Mixed cypress-ash swamp	Florida	5	0	TN	90	+			+			Boyt et al. 1977
				TP	98	++	+					
Cypress domes	Florida		0	TN	98	++		+	++			Fritz and Helle 1978
				TP	97	++		+				Odum and Ewel 1980; Odum et al. 1976
Riverine swamp	South Carolina		0	NO_3-N	0							
				TP	50	++		+				Kitchens et al. 1976

Note: *: indicates removal based on concentration
O: organic substrate
I: inorganic substrate
++: major removal mechanism
+: secondary mechanism

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Northern peatlands include sphagnum bogs, ombrotrophic bogs, minerotrophic bogs, fens, sedge meadows, cedar swamps, and similar wetland types. The various types of northern peatlands can be further divided into the two major categories of bogs and fens. Bogs include wetlands dependent entirely on precipitation for nutrients. They are also characterized by largely organic soils which have developed on top of what was originally a fen. Bogs have acid soil maintained and produced by humic acids originating primarily from sphagnum moss. Bogs may include spruce-tamarack swamps, ericaceous shrub swamps, or treeless blanket bogs (Gorham 1979).

Fens are wetlands which obtain nutrients primarily from surface or groundwater sources. Soil pH is neutral to alkaline, and varies widely in organic content. The types of fens range from grass, sedge, or shrub meadows to cedar swamp forests.

Northern peatlands generally have good removal efficiences for P and N. Phosphorus is removed mainly by adsorption. Vegetation uptake is not a major removal mechanism. Nitrogen is removed primarily by microbial denitrification (Richardson et al. 1976, 1978). Because of their more controllable water levels, bogs may have more potential for use in wastewater application systems. Since fens have more complex sources of water inflow and outflow, which are more difficult to control, they have lower potential in this respect.

The long-term potential of using northern peatlands for wastewater application may in fact be limited, and has been questioned. Burke (1975) stated that acid peatlands had a limited long-term ability to store excess phosphorus and potassium. Richardson et al. (1978) stated that net long-term losses of nutrients from acid wetlands generally may be high. Addition of alkaline wastewater to acid wetlands could significantly alter the pH, nutrient regime and result in major ecological changes.

Non-tidal freshwater marshes include deep and shallow marshes, prairie potholes, reed swamps, and lacustrine marshes. They are distinguished from northern peatlands primarily by essentially permanently inundated soils. Dominant plants usually include cattail, bulrush, giant reed, and similar species. Submerged and floating aquatic vascular plants are also common. Soils are typically high in clays and silt, with widely varying levels of organics.

In contrast to northern peatlands, adsorption does not seem to be the major phosphorus removal mechanism in non-tidal freshwater wetlands. Instead, chemical precipitation (i.e., formation of insoluble phosphate or sulfide precipitates) and uptake by plants appear to be the primary mechanisms of nutrient uptake. Aquatic vascular plants remove nutrients from the water column, but also translocate sediment nutrients upward (Prentki et al. 1978). Periphyton growth may also rapidly remove nutrients from the water column, although this may represent a relatively temporary sink (Kadlec 1979).

Nutrient removal effectiveness is therefore not as predictable or well known in non-tidal freshwater wetlands. In non-tidal freshwater wetlands, emergent and submerged macrophytic plants and periphyton are major sites of nutrient uptake (some soil adsorption also occurs). Nutrient uptake dynamics are controlled more by seasonal growth patterns and the hydrologic regime. Water constitutes a more active factor in nutrient removal, since it ultimately controls plant growth and soil nutrient adsorption. Nevertheless, application of wastewater to this type of system possibly poses less of an ecological risk, since non-tidal freshwater wetlands are ecosystems that are typically alkaline, eutrophic, and of low diversity.

In comparing all of the general categories of wetlands reviewed, the conditions favoring nutrient removal are as follows:

- Conditions favoring phosphorus removal:
    - Organic soil in poor nutrient regimes
    - Vegetation limited by phosphorus supply
    - Presence of Fe and Al compounds
- Conditions favoring nitrogen removal:
    - Reduced soil-water interface (denitrification)
    - Vegetation limited by N

- Conditions favoring nitrogen and phosphorus removal:
  - Low or no energy subsidy to the wetland by tides, wave action, streamflow, etc.

A summary of the primary nutrient removal mechanisms in northern peatlands, and non-tidal freshwater wetlands, and other wetland categories is provided in Table 3.1-6. This information can be utilized in future studies concerning effects of wastewater on wetland systems in USEPA Region V.

Table 3.1-6. Summary of the most important nutrient uptake processes in different wetland ecosystems in Region V (from Heliotis 1982).

Wetland Type	Nitrogen	Phosphorus
Northern Peatlands *good removal*	Denitrification Vegetational uptake NH_4^+ adsorption to peat	Adsorption to peat Vegetational uptake
Nontidal Freshwater Marshes *variable removal*	Denitrification Macrophytic uptake Periphytic uptake	Chemical Precipitation Macrophytic uptake Periphytic uptake Adsorption to substrate
Tidal Freshwater Marshes *poor/no removal*	Denitrification Vegetational uptake Tidal transfer	Litter uptake Vegetational uptake Tidal transfer
Brackish/Salt Marshes *variable removal*	Denitrification Macrophytic uptake Periphytic uptake Tidal transfer	Macrophytic uptake Periphytic uptake Adsorption to peat Tidal transfer
Southern Swamps *good removal*	Denitrification Macrophytic uptake Periphytic uptake	Macrophytic uptake Periphytic uptake Adsorption to substrate
Sawgrass Marshes *poor removal*		Adsorption to substrate Litter uptake

3.1.3 Accumulation of Other Dissolved Substances

In addition to nitrogen and phosphorus, other materials and dissolved substances are present in wastewater which may affect the receiving wetland. These include organic (non-toxic) compounds, chloride and other similar dissolved ions such as sodium, potassium, magnesium, calcium. Common means to measure the effects of these compounds and ions include analysis of chemical oxygen demand (COD), dissolved oxygen (DO), pH, alkalinity, salinity, redox potential, and conductivity. Various sulfur compounds, including hydrogen sulfide, sulfite and sulfate may also be introduced into a wetland by applied wastewater.

BOD is a water quality parameter measured at all sewage treatment plants. Some data have been acquired for wetlands receiving treated sewage at a number of locations. Reductions in BOD during passage of the wastewater through wetlands have been documented by Yonika and Lowry (1979), Hartland-Rowe and Wright (1975), Seidel (1976), and others.

Little is actually known about the chemistry of sulfur compounds. Wetlands are known to be capable of producing hydrogen sulfide. Odum (1978) has indicated that wetlands may play an important role in the global sulfur cycle.

Chloride is frequently present in fairly high levels in wastewaters, in contrast to its relatively low concentration in receiving water bodies or groundwater. It also is relatively inactive both physically and chemically, and its concentration is relatively unaffected by biological processes. It is therefore valuable as a tracer for identification of water movements and dilutions in wetland wastewater treatment systems. Kadlec (1978) used chloride (as well as other parameters) to measure changes in water quality as a function of distance from the wastewater outfall at Houghton Lake, Michigan.

Although wetlands appear to act as buffers with respect to factors such as pH, hardness, and alkalinity, there is a limit to the ability of wetland to adjust to major changes in these parameters. For example, prolonged exposure to the alkaline waters from a sewage treatment plant undoubtedly will alter the chemical nature of an acid bog. The Kincheloe, Michigan, wastewater application site is an excellent example of the conversion of an acid bog to a cattail marsh, produced by a shift in pH (Kadlec, et al. in preparation). Major changes such as these may result in the erosion of wetland soils, changes in wetland chemistry, or changes in vegetative composition that subsequently could affect the use of the wetland by wildlife.

3.1.4 Accumulation of Trace Metals

Municipal wastewater may contain varying amounts of trace metals (Table 3.1-7). Trace metals that could have potential toxic ecological effects include mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), copper (Cu), and zinc (Zn). The toxicity of metals and their tendency to accumulate in food chains are potential problems associated with introducing wastewater into a wetland. This is because wetland sediments may act as a sink for the trace metals. Some species of plants also have an absorptive capacity for trace metals, can bioaccumulate them, and continue to cycle trace metals in wetland food webs.

To date, little is known concerning where and to what extent metals accumulate in the wetland ecosystem. Few studies have been conducted that have determined how trace metals are cycled within wetland ecosystems. Wolverton and McKown (1976) showed that water hyacinths are able to absorb lead at a fairly significant rate. Lee et al. (1976) examined the uptake of heavy metals by various plant parts in waters with different metal concentrations. Chromium appeared to be taken up and concentrated in the root zone, and other metals behaved in a similar fashion. Transect studies of the fate of the trace metals in waters entering wetland ecosystems have been conducted at a few sites. Semkin et al. (1976) found elevated levels of copper, zinc, lead, cadmium, and arsenic in the vicinity of a wastewater discharge. Carriker and Brezonik (1975) reported elevated levels of heavy metals in cypress domes receiving wastewaters in Florida. In contrast, Boyt et al. (1977) did not observe any elevated levels of zinc, copper, or lead in a Florida wetland receiving a municipal wastewater discharge. Distributional patterns of different compounds within plants vary so widely that no generalizations can be made at this time (Benforado 1981).

Table 3.1-7. Trace element levels in raw and treated municipal effluents (from USEPA 1977).

		Primary effluents, mg/l	Secondary effluents, mg/l
Element	Untreated wastewater[a], mg/l	National[a]	National[a]
Arsenic	0.003	0.002	0.005-0.01
Cadmium	0.004-0.14	0.004-0.028	0.0002-<0.02
Chromium	0.02-0.700	<0.001-0.30	<0.010-0.17
Copper	0.02-3.36	0.024-0.13	0.05-0.22
Iron	0.9-3.54	0.41-0.83	0.04-3.89
Lead	0.05-1.27	0.016-0.11	0.0005-<0.20
Manganese	0.11-0.14	0.032-0.16	0.021-0.38
Mercury	0.002-0.044	0.009-0.035	0.0005-0.0015
Nickel	0.002-0.105	0.063-0.20	<0.10-0.149
Silver	--	--	--
Zinc	0.030-8.31	0.015-0.75	0.047-0.35

a. Source: USEPA 1977

A summary of data on the uptake of various heavy metals by species of freshwater marsh plants was prepared by Stanley Consultants (1977). This information is presented in Table 3.1-8. The rate and extent of metal uptake is dependent on the particular trace metal and the species of plant involved. Concentrations of several metals by marsh plants decreased rapidly with increasing distance from a landfill leachate source. Some, such as lead, became bound to sediments; others, such as zinc and cadmium, were taken up by the vegetation.

The above results were compared with the results of similar studies on saltwater marsh plants, and it was determined that freshwater marsh vegetation may be able to take up greater quantities of heavy metals than saltwater marsh vegetation (Stanley Consultants 1977). The long-term effects of heavy metals on wetlands may be of more concern than the short-term effects, due to the potential for saturation of sediments and/or release of heavy metals stored in sediments when water or sediment quality conditions change.

Metal retention is related to a wide variety of factors, including type of metal, pH, and organic content of soil hydrologic conditions, accretion and erosion rates, and type of plant (Giblin 1983; Tiffin 1977 in Benforado 1982). The percentage of metals removed varies widely among types of metals and among types of wetlands. Some metals such as lead may be effectively retained under low loading, but many others, such as copper (Cu), cadmium (Cd), and zinc (Zn), appear to pass through the system in varying degrees. In some wetlands, less than half of the Cu, Cd, and Zn entering the system was retained (Table 3.1-9). It has been shown that soil pH varies widely with organic matter content between different types of wetland systems. This is due to varying amounts of oxidation, which is largely dependent on hydrology, sediment permeability and detrital production. Generally, low pH soils are characterized by high levels of organic material. In some instances, soils high in organic matter have been shown to retain higher levels of trace metals than those high in mineral content. However, the actual ability of an organic soil varies with pH (lower ability at low pH), and hydrologic regime as these affect sedimentation and water chemistry (especially oxygen levels) (Vestergaard 1979; Giblin 1983).

Table 3.1-8. Trace metal uptake by freshwater marsh plants (adapted from Stanley Consultants 1977).

Metal	Kilograms/Hectare[a] High	Kilograms/Hectare[a] Low	Pounds/Acre[b] High	Pounds/Acre[b] Low
Iron (Fe)	123	4.5	110	4.0
Manganese (Mn)	296	2.0	264	1.8
Zinc (Zn)	30	0.3	27	0.3
Cadmium (Cd)	0.16	0.02	0.14	0.02
Cobalt (Co)	0.03	0.01	0.03	0.01
Chromium (Cr)	0.4	0.1	0.4	0.1
Copper (Cu)	15.9	0.04	14.2	0.04
Molybdenum (Mo)	0.08	0.002	0.07	0.002
Nickel (Ni)	0.44	0.01	0.39	0.01
Lead (Pb)	1.12	0.11	1.00	0.10

---

[a] Reported values are from various species of plants in widely varying environments.

[b] Derived by multiplying kg/ha by 0.892.

Table 3.1-9. The percentage of the metal coming into a wetland which subsequently leaves the system (from Giblin 1983).

		Percentage of Trace Metals							
	Method	Cu	Cd	Cr	Mn	Fe	Pb	Zn	Hg
Papyrus swamp									
Africa[1]	I/O				6%	3%			
Bogs									
Mass[2]	I/O						2%		
Mass[2]	I/SA						15%		
Moor House[3]	I/SA	60%				0%	0%	50%	
Salt Marshes									
N.C.[4]	I/O				41%	30%		100%	
Del.[5]	I/SA						0%		
Conn.[6]	SP				50%				
Georgia[7]	I/SA	78%	83%		36%	0%			88%
Sewage added									
Mass.[8]	I/SA	51%	85%	55%	73%	76%	40%	72%	0%
Dredge Spoil Effluent									
Georgia[9]	I/O	52%	85%		53%	51%		81%	

1-Gaudet 1976, 2-Hemond 1980, 3-Clymo 1978, 4-Wolfe et al. 1973, 5-Church et al. 1981, 6-McCaffrey 1977, 7-Windom 1975 & Windom et al. 1976, 8-Giblin 1982 & Breteler et al. 1981 a, 9-Windom 1977. The methods used to construct the budgets were: I/O = input/ sediment accumulation, and SP = sediment profiles.

In summary, although the biological effects of trace metals in wastewater on aquatic communities are fairly well known (Tsai 1975, 1978; Welch 1980), little is known about the effects of these metals on wetlands. The studies conducted by the University of Florida on cypress domes are the most detailed to date (Ewel and Odum 1979), but the year-round discharge potential in that climate and the characteristics of the wetlands are considerably different than in the upper Midwest. Trace metal studies in wetlands receiving wastewater are also being conducted at Houghton Lake, Michigan (Hammer and Kadlec 1983; Kadlec 1978) and at Drummond, Wisconsin by a consortium of researchers from several campuses of the University of Wisconsin. Research on trace metals is also being conducted at Brillion Marsh, Wisconsin by USFWS (in preparation) and the Wisconsin Department of Natural Resources. These studies are discussed in Section 3.2.1.5.

3.1.5 Accumulation of Refractory Chemicals

Marsh plants are capable of removing a variety of refractory chemicals from water, including surfactants, phenols, and agricultural pesticides (Seidel 1976) (the term "refractory" indicates that these substances are resistant to decomposition). These compounds, which are toxic in low concentrations, break down slowly and tend to accumulate in living organisms or on adsorptive surfaces.

Seidel (1976) reported that wetland ecosystems were capable of rapidly absorbing compounds such as phenol, pyridine, and aniline. Analyses of marsh muds and organisms collected after hydrocarbon spills have shown uptake of hydrocarbon material (Burns and Teal 1971). Whelan et al. (1976) determined that a chronic hydrocarbon input to a shallow marsh was absorbed, presumably due to microbial processes within the marsh. Water hyacinths have been reported to take up phenol (Wolverton and McKown 1976). However, the long-term effects of the introduction of refractory chemicals into the wetland ecosystem are as yet unknown.

3.1.6 Changes in Soils and Sediments

The types and amounts of soils in wetlands vary considerably among wetlands. Many wetlands in the upper Midwest have large accumulations of peat and other organic materials, while river-margin wetlands may be situated on more mineral soils with little organic accumulation. Brown et al. (1979) summarized the factors producing various types of wetland soils (Figure 3.1-15). Soils in wetlands are primarily a function of the alluvial deposition rate, the biogenic accumulation rate, and the rate of turnover (flushing) of water (Figure 3.1-15). Most wetland sediments are a mixture of peats and inorganic sediments.

Soils constitute the primary sink for phosphorus in many wetlands (Nichols 1980a,b,c). There are several processes by which phosphorus is incorporated into soil. There is some evidence that precipitation of calcium phosphate is a significant phosphorus sink (Wetzel 1975). Iron and aluminum, in conjunction with humic acids, are believed to participate in the sorption process for phosphorus. Ion exchange is another potential route for immobilization of nutrients (see Section 3.1.2). The process of soil building is therefore of great importance to the ultimate capacity of a wetland to immobilize phosphorus. In addition, it has been noted that denitrifying bacteria, which control the principal nitrogen removal processes, are present on the surfaces of the soils and sediments.

Soil building occurs through the mechanisms of litter fall and sedimentation within the wetland. Soil building is promoted by anaerobic conditions during inundation, and by low temperatures. These conditions prevent the oxidative decomposition of organic material arriving at the soil surface. A potentially significant mechanism for soil removal may be chemical leaching of acidic soil with basic wastewater. There is some evidence that chemical leaching has occurred at Kincheloe, Michigan (Kadlec et al. in preparation). Erosion caused by scouring during floods may also be an important cause of soil removal.

The rates of peat accumulation in some wetlands have been determined by measurement of radioactive isotopes. The locations of isotopes deposited as a result of nuclear test fallout of the 1950's can be identified within the soil structure, and these horizons then can be used to determine sedimentation rates in the intervening years. Typical estimates of 1 millimeter (mm) of sediment accumulation per year have been reported (Boto and Patrick 1975).

Sediments entering wetlands in wastewater discharge are measured at the treatment plant outfall as suspended solids. In some cases, these materials are removed by physical filtration. However, wetlands may also generate large amounts of suspended solids (such as algal detritus). Boto and Patrick (1975) summarized the limited information concerning suspended solids cycles in wetlands. Measurements of suspended solids in a Michigan peatland (Houghton Lake) treated with wastewater were summarized in Kadlec and Tilton (1979), Hammer and Kadlec (1982). These solids are important from the standpoint of nutrient cycling because they typically contain 2.0% nitrogen and 0.2% phosphorus by dry weight.

3.2 Issue Category II: Wetland Structure and Function - Biological Components

3.2.1 Effects on Plant Communities

Five major types of impacts on wetland plant communities can result from wastewater application. These are as follows:

- Long-term changes in species composition;
- Long-term changes in relative areal distribution of component species;
- Changes in biomass, growth, and production;
- Changes in detrital cycling; and
- Transfer of potentially toxic trace metals or other materials into the food chain.

Because little is known concerning the long-term ecological effects of wastewater application in wetlands (Guntenspergen and Stearns 1983), these constitute major issues. This section examines each of the above issues in detail based on the existing literature. Guntenspergen and Stearns (1983) present a general overview of wetland ecology and the possible ecological effects of applied wastewater. Figure 3.2-1 summarizes the potential impacts on plant communities. Methodologies available to address impacts are outlined in the

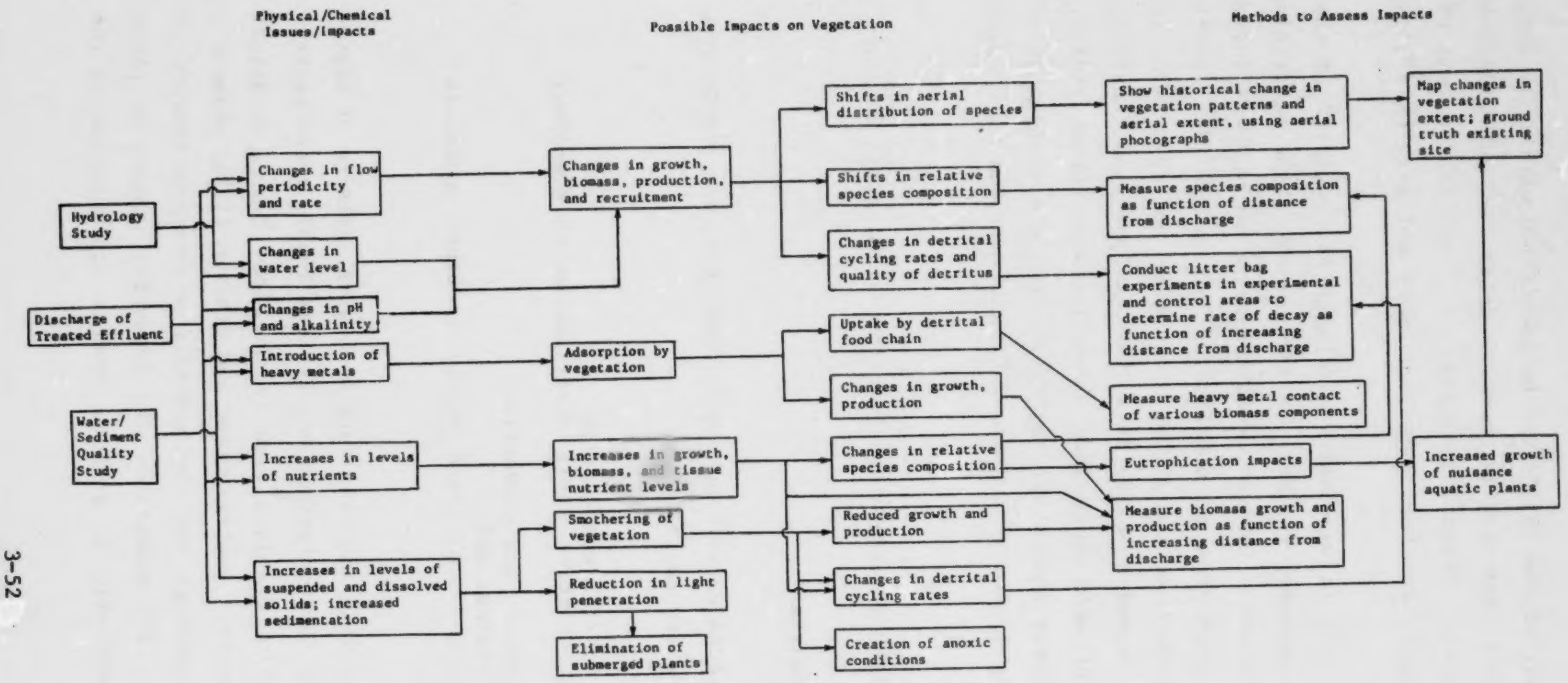

Physical/Chemical Issues/Impacts
Possible Impacts on Vegetation
Methods to Assess Impacts
Hydrology Study
Discharge of Treated Effluent
Water/ Sediment Quality Study
Changes in flow periodicity and rate
Changes in water level
Changes in pH and alkalinity
Introduction of heavy metals
Increases in levels of nutrients
Increases in levels of suspended and dissolved solids; increased sedimentation
Changes in growth, biomass, production, and recruitment
Adsorption by vegetation
Increases in growth, biomass, and tissue nutrient levels
Smothering of vegetation
Reduction in light penetration
Elimination of submerged plants
Shifts in aerial distribution of species
Shifts in relative species composition
Changes in detrital cycling rates and quality of detritus
Uptake by detrital food chain
Changes in growth, production
Changes in relative species composition
Reduced growth and production
Changes in detrital cycling rates
Creation of anoxic conditions
Show historical change in vegetation patterns and aerial extent, using aerial photographs
Measure species composition as function of distance from discharge
Conduct litter bag experiments in experimental and control areas to determine rate of decay as function of increasing distance from discharge
Measure heavy metal contact of various biomass components
Eutrophication impacts
Measure biomass growth and production as function of increasing distance from discharge
Map changes in vegetation extent; ground truth existing site
Increased growth of nuisance aquatic plants

Figure 3.2-1. Impact factor train for vegetation (figure created by S.D. Bach, WAPORA, Inc., 1983).

Technical Support Document that accompanies this report. Potential impacts on plant health are discussed in Section 3.3.2.

3.2.1.1 Long-term Changes in Species Composition

The introduction of wastewater to a natural wetland may change the species composition of the plant community by:

- Changes caused by raising or lowering water levels, or by altering the periodicity of flooding (hydrology);
- Changes caused by increasing concentrations of potentially toxic trace metals; and
- Changes in salinity, alkalinity, hardness, pH, and other chemical characteristics.

Changes in water level are especially important in influencing the plant species composition of a wetland. Both frequency and duration of flooding play central roles in determining the type of wetland formed and maintained (Novitzki 1978). The types of surface and subsurface drainage patterns also determine the nature of discharge into and through the wetland (Novitzki 1978). If this pattern is altered, wetland vegetation may be affected. The species composition of lowland forests in particular is affected by water level changes (Bedinger 1978). For example, it has been demonstrated that duration and frequency of flooding, groundwater level, discharge characteristics, soil oxygen levels, and other soil factors all exert a major influence over the distribution of bottomland forest tree species (Bedinger 1978) (Figure 3.2-2). Most species of trees are not able to withstand more than two years of permanent flooding due to anaerobic soil conditions (Bedinger 1978).

A major control is exerted by the effects of water level on seedling survival; differential seedling mortality may be a significant factor controlling species composition in these communities. Seedling survival depends primarily on the ability to withstand anaerobic conditions. Flooding during the growing season also is of particular importance (Bedinger 1978). Therefore, any major changes in volume, rate, or periodicity of discharge to a wetland caused by wastewater application could alter the species composition of the vegetation in this manner.

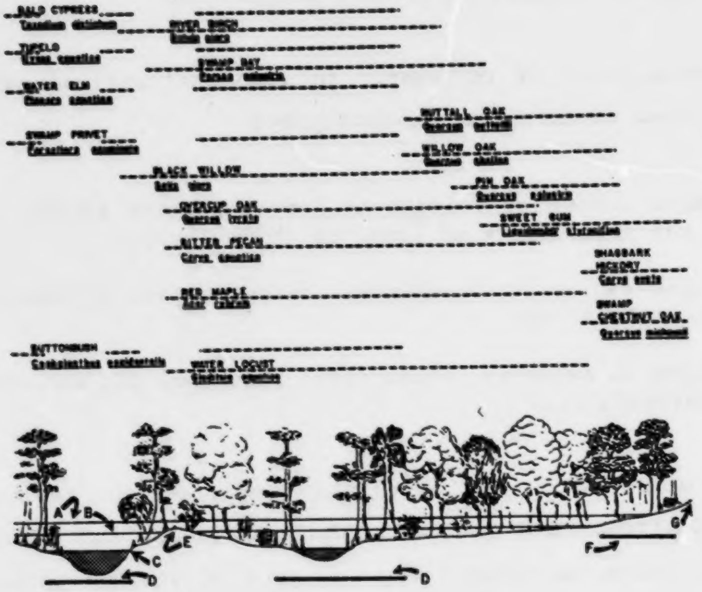

BALD CYPRESS
Taxodium distichum
RIVER BIRCH
Betula nigra
TUPELO
Nyssa aquatica
SWAMP BAY
Persea borbonia
WATER ELM
Planera aquatica
NUTTALL OAK
Quercus nuttallii
SWAMP PRIVET
Forestiera acuminata
WILLOW OAK
Quercus phellos
BLACK WILLOW
Salix nigra
PIN OAK
Quercus palustris
OVERCUP OAK
Quercus lyrata
SWEET GUM
Liquidambar styraciflua
BITTER PECAN
Carya aquatica
SHAGBARK HICKORY
Carya ovata
RED MAPLE
Acer rubrum
SWAMP CHESTNUT OAK
Quercus michauxii
BUTTONBUSH
Cephalanthus occidentalis
WATER LOCUST
Gleditsia aquatica
A
B
C
D
E
D
F
G

Figure 3.2-2. Section of a Mississippi delta lowland hardwood wetland illustrating plant distribution (horizontal bar) in relation to a permanently flooded stream and an oxbow. (A-highest possible flood level; B- mean annual high water level; C- mean annual low water level; D- low sites; E- natural levee; F- high site; G- upland area)(from Fredrickson 1978).

Algal populations in wetlands are affected by wastewater in the same manner. Changes may occur in species composition and abundance as well as net primary production (Benforado 1981; Brown 1981). Increased levels of nutrients may cause some opportunistic species to grow faster and to out-compete slow-growing species. This may also produce shifts in species composition. Because of these potential changes, several studies concerned with wastewater application to wetlands have been conducted specifically to consider the potential impacts of water level changes on vegetation species composition (Bayley 1983).

Other factors related to wastewater application that could potentially change plant species composition include the addition of elevated levels of nutrients and trace metals. Elevated nutrient levels could result in increased growth of some species, whereas uptake of heavy metals could suppress growth rates in other species. Both factors could produce differential growth and, consequently, shifts in species composition. For example, Kadlec et al. (1978) documented large-scale, short-term (over a period of 5 years) changes in plant species composition that resulted from discharging treated sewage to a sedge-shrub peatland in Michigan. The authors touched that long-term changes in species composition also occur. Ewel (1976), Ewel and Odum (1978, 1979), and Brown (1981) documented changes in the species composition of Florida cypress dome vegetation receiving treated sewage effluent. Bevis (personal communication) and Kadlec et al. (in preparation) documented major vegetation changes in an acid bog at Kincheloe, Michigan, that has received treated sewage over a period of more than 20 years. In studies at Drummond, Wisconsin, short-term (two-year) changes in plant species composition have not yet been observed, but potential long-term changes are being monitored (Reim n.d., Knighton n.d.).

Whigham and Simpson (1976) observed few changes in species composition in a tidal freshwater marsh in Delaware which received treated effluent, probably due to the already highly eutrophic nature of the river and rapid removal of wastewater by tidal action. Zoltek et al. (1979) noted a major increase in understory plants in a Florida cypress dome receiving treated wastewater.

3.2.1.2 Changes in Plant Biomass, Growth, and Production

Changes (typically increases) in plant biomass, growth, and rates of production may result when treated wastewater is applied to a wetland. For example, in certain wetlands, such as northern bogs and peatlands, the species composition is believed to be controlled to a large extent by nutrient availability (Wentz 1975). Tamm (1951 in Wentz 1975) reported that the addition of nutrients to a peatland resulted in an invasion of birch, and Moizuk and Livingston (1961 in Wentz 1975) concluded that red maple could not become established in marshes due to insufficient nutrient levels. Wastewater applications to wetlands produce nutrient-rich conditions that enables the invasion by non-characteristic species (Guntenspergen, unpublished; Kampi 1971; Suraleka and Kampi 1971 in Guntenspergen and Stearns 1981).

Changes in pH and alkalinity could play a significant role in changes in growth, biomass, and production, which in turn may lead to shifts in species composition. Such alterations in water chemistry could have particularly significant effects on species composition in acid bogs or alkaline fens. For example, the Drummond, Wisconsin study evaluated a sewage discharge into a small ombrotrophic bog beginning in 1979 (Guntenspergen et al. 1980 in Guntenspergen and Stearns 1981). Guntenspergen and Stearns (1981) reported that after application exposed peat at the Drummond bog was less firm, and sphagnun moss cover was disappearing as a direct result of higher pH. Weedy and exotic plants, including willow herb (Epilobium), cattails (Typha) and many others invaded exposed peat along the effluent pipeline. Bulrushes such as Carex oligosperma and C. trisperma (infrequent bog species) have also increased in density and frequency (Guntenspergen and Stearns 1981).

Studies of submerged aquatic plants in greenhouses and experimental ponds have shown that species responded differently to various combinations and levels of phosphorus and nitrogen (Mulligan et al. 1976, Mulligan and Baranowski 1969, both in Guntenspergen and Stearns 1981). Guntenspergen and Stearns (1981) reported that moderate fertilization increased growth of certain submerged macrophytes, but higher nutrient levels shifted the competitive balance toward phytoplankton.

Turner et al. (1976) demonstrated that biomass and production of emergent vegetation in a Louisiana freshwater marsh receiving treated wastewater from a fish processing factory was significantly higher than that of control sites. Root tissue levels of N an P were significantly higher in experimental plots. Less than five percent of the total N and P added was taken up by the vascular plants at the site. Guntenspergen (unpublished in Guntenspergen and Stearns 1981) noted that fertilization of a freshwater marsh increased the standing crop of bulrush (Scirpus validus) and bur-reed (Sparganium eurycarpum). Biomass of tearthumb (Polygonum natans) increased in the bulrush but not in the bur-reed stands. Ewel (1976) and Ewel and Odum (1978, 1979) reported a dramatic increase in the growth of duckweed (Lemna minor) as a result of discharging treated municipal wastewater to a cypress dome in Florida. Ewel and Odum (1978, 1979) also noted a marked increase in biomass of understory plants in the same cypress domes (Figure 3.2-3). Growth of cypress trees receiving treated wastewater over a period of 40 years was shown to be significantly higher than those in a control area (Nessel 1978). However, Brown (1981) reported that stand history rather than phosphorus input affected plant biomass in Florida cypress domes.

Changes in biomass and production have been addressed in several other previous studies. Kadlec et al. (1979) and Tilton and Kadlec (1979) showed that cattail biomass increased significantly in the immediate vicinity of a pipe discharging treated wastewater to a sedge-shrub peatland in Michigan. Increases in tissue levels of nitrogen and phosphorus by plants in plots receiving treated effluent also were demonstrated in these studies. The increase of phosphorus concentrations in live tissue was positively related to levels of applied nutrients for certain species. Brown (1981) reported increased net daytime photosynthesis, plant respiration, and gross primary productivity in a Florida cypress dome receiving sewage. Increased biomass or growth of wetland plants as a result of wastewater application has been demonstrated for bottomland hardwood swamps by Boyt et al. (1976), by Mudroch and Capobianco (1979) for emergent Glyceria marshes, and by Valiela et al. (1975) for salt marshes in Massachusetts.

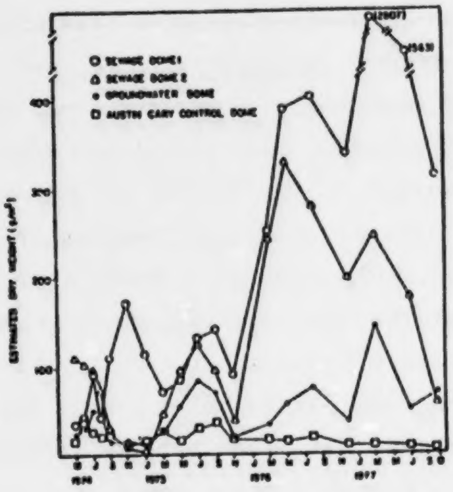


Figure 3.2-3. Changes in biomass of understory vegetation in Florida cypress domes receiving munincipal wastewater (from Ewel and Odum 1978).

3.2.1.3 Long-term Changes in Areal Distribution of Wetland Plants

Several workers have used aerial photographs to examine changes in the horizontal extent of wetland communities. Knighton (1980) monitored both changes in species composition and areal extent of plant communities in a bog receiving treated waste at the Drummond, Wisconsin site. Kadlec and Hammer (1981, 1982, 1983) employed infrared aerial photographs to delineate major plant communities in a peatland at Houghton Lake, Michigan. Kadlec et al. (in preparation) studied long-term changes in the areal extent of vegetation at the Kincheloe, Michigan site. Other than the Kincheloe studies, no truly long-term research (more than 10 years) has been conducted in which areal distribution was examined.

3.2.1.4 Changes in Detrital Cycling

The introduction of treated wastewater into wetlands could alter rates of plant detritus cycling. Hodson et al. (1982) discussed an approach to studying the impact of environmental stress on wetlands. This approach assumes that wetlands are detritus-based ecosystems. A detritus-based system is one in which much of the carbon and energy originating from primary production passes through "compartments" of detritus and microbial biomass before becoming available to consumers at higher trophic levels in wetland food webs. Hodson et al. (1982) examined plant materials from a variety of wetland plant species and found that they consisted primarily of lignocellulose, a macromolecular complex consisting of polysaccharides and lignin. They concluded that most of the annual primary production in wetlands was in the form of lignocellulose. Any events that alter the rate of transformation of lignocellulose in a wetland will therefore eventually affect the abundance, diversity, and production of higher trophic levels.

Since detrital material plays an important role in wetland food chain energetics (Tilton and Schwegler 1979; Hodson et al. 1982), changes in cycling or availability of these materials produced by the application of wastewater, represent a significant negative impact. For example, the rate of detrital breakdown is known to increase with increasing levels of dissolved nutrients

(Hynes and Kaushik 1969). Changes in nutrient levels caused by added wastewater therefore could alter the amounts and quality of available detritus, thereby affecting freshwater animals that may depend on the detrital food web (Tilton and Schwegler 1979). Additional organic matter entering the wetlands as suspended particulates could also be available for decomposition. Changes in water level also could affect rates of detrital cycling by producing changes in populations of organisms which decompose plant material (i.e., microbes as well as invertebrates). Some studies have also shown that the litter layer may be an important nutrient sink (Richardson et al. 1976; Chamie 1976). Alteration of rates of detrital decomposition can therefore provide an estimate of one important impact of wastewater application on wetlands. For example, Sutherland and Bevis (1979) observed a buildup of cattail straw (detritus) at the Vermontville, Michigan site, a volunteer wetland that received treated wastewater for six years. Kadlec (1981) reported buildup of plant detritus at the Houghton Lake, Michigan site (Figure 3.2-4). Therefore, a number of different types of changes in detrital cycling may occur when wastewater is added to a wetland. However, whether these provide a net benefit or a net adverse effect on wetland food chains and nutrient cycles has not yet been determined.

Because of the potential for changes in detrital cycling rates, investigators have attempted to measure the rate of decomposition of vegetation in wetlands receiving treated effluent. Chamie (1976) used the litter bag method to study the effects of added nutrients on decomposition rates. There were no significant differences in decomposition rates among plots receiving added nutrient salts. Weight loss never exceeded 42 percent in the first year, and the pattern of element loss from the detritus was similar to previous studies. Although no significant differences in weight or element loss rates of decomposing vegetation were observed in the first year, differences probably would have developed after two or three years. The very slow overall rates of decomposition observed were related to the distinctive physical, chemical, and biological features of peatlands. Ewel and Odum (1979) reported no differences in the rates of decomposition of cypress needles in litter bags from control sites and from a cypress dome that received treated effluent (Figure

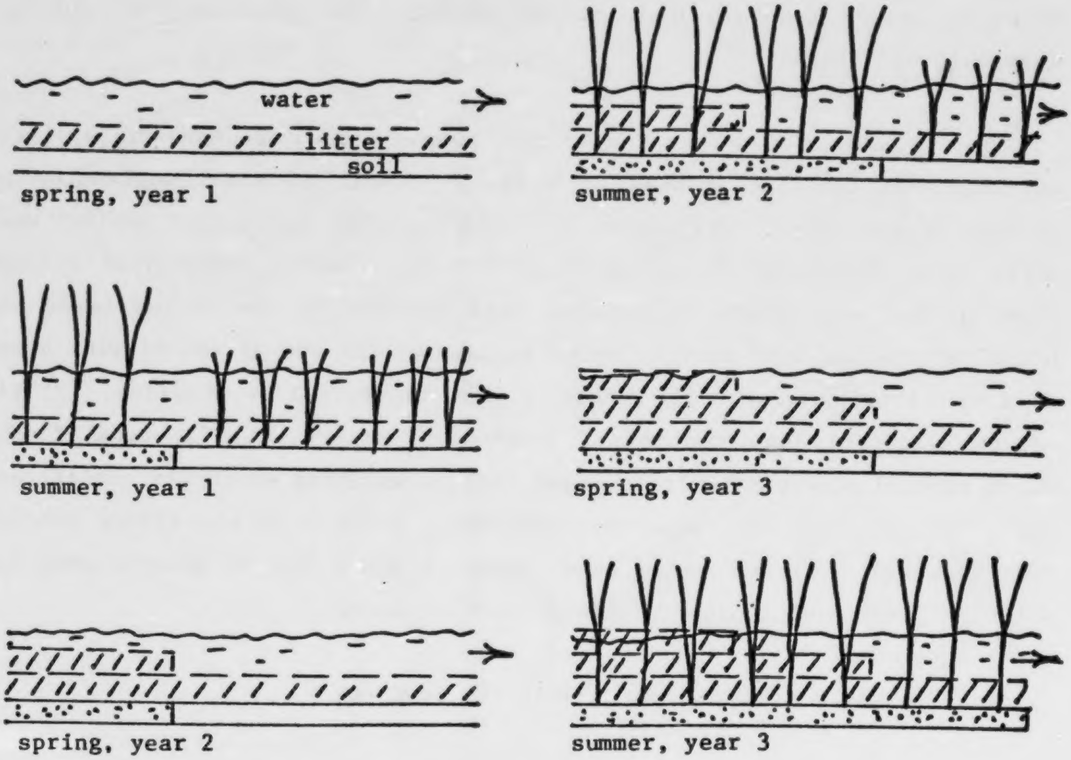

water
litter
soil
spring, year 1
summer, year 2
summer, year 1
spring, year 3
spring, year 2
summer, year 3

Figure 3.2-4. Litter build-up in the Houghton Lake, Michigan, peatland during a three year period (from Kadlec 1981).

3.2-5). Decomposition probably was not affected because heavy development of duckweed helped maintain high oxygen levels, thus preventing or minimizing anaerobic conditions.

Ewel (1976) showed that the species composition of decomposer populations of fungi and bacteria changed as a direct result of added wastewater in a Florida cypress dome. Whigham et al. (1980) studied effects of applied wastewater on a freshwater tidal marsh in Delaware, and reported that nutrients from applied chlorinated wastewater were retained by the litter layer for a brief period, but were then released rapidly at the end of the growing season. This was attributed to: (1) damage to the vegetation by chlorine; (2) rapid natural rates of decomposition of freshwater macrophytes; (3) tidal flushing which removed accumulated litter; and (4) the existing eutrophic conditions of the river in which the marsh was situated. Whigham et al. (1980) concluded that growth and decomposition rates probably would not be altered greatly by additional nutrient inputs in this particular marsh.

3.2.1.5 Transfer of Trace Metals Into the Food Web

Secondarily treated sewage effluent typically is characterized by slightly elevated levels of trace metals (USEPA 1973) (Table 3.1-7). Wetlands that receive treated waste from certain types of industrial plants may, however, be exposed to higher levels of trace metals such as cadmium (Cd), zinc (Zn), magnesium (Mg), manganese (Mn), chromium (Cr), mercury (Hg), and the anion cyanide. Because trace elements are present in treated wastewater, a potential exists for transfer into the wetland food chain via plant uptake and the detrital cycling. Table 3.1-7 summarized the range of values for trace metal uptake by freshwater wetland plants. These values represent a wide range of habitats and species, and illustrate the highly variable nature of this process.

Wickum and Ondrus (1980) studied the uptake of trace elements by vegetation in a peat bog that received treated wastewater. The data are based on the first two years of operation. To date there have been no significant deleterious effects of trace elements on foliar growth of dominant species of bog vegetation. However, only very low levels of trace metals were introduced

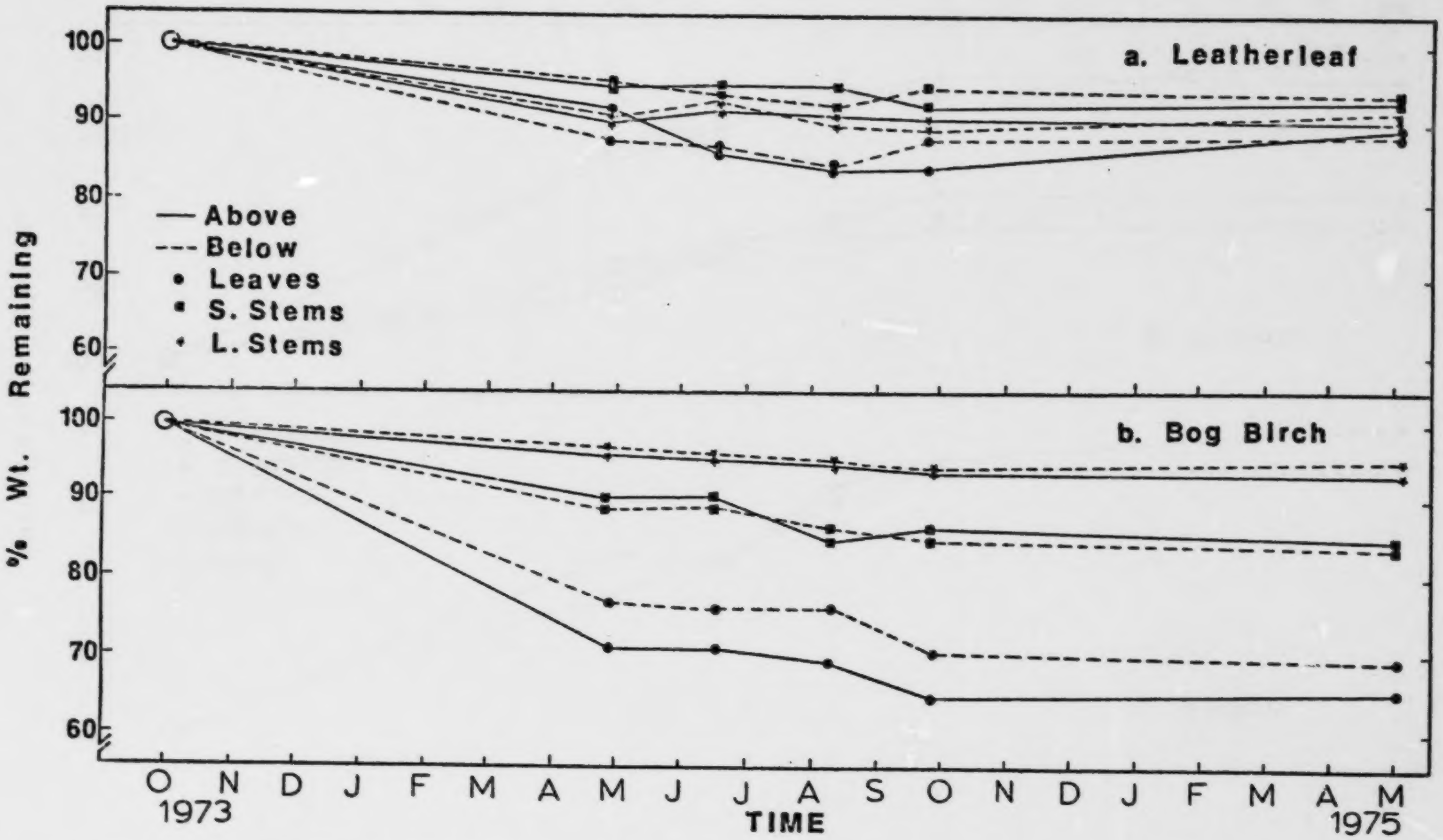


Figure 3.2-5. Percentages of original weight remaining in leaves, small and large stems of (a) leatherleaf, (b) bog birch, (c) sedge and (d) willow placed September 1973 by aboveground and belowground positions (from Chamie 1976).

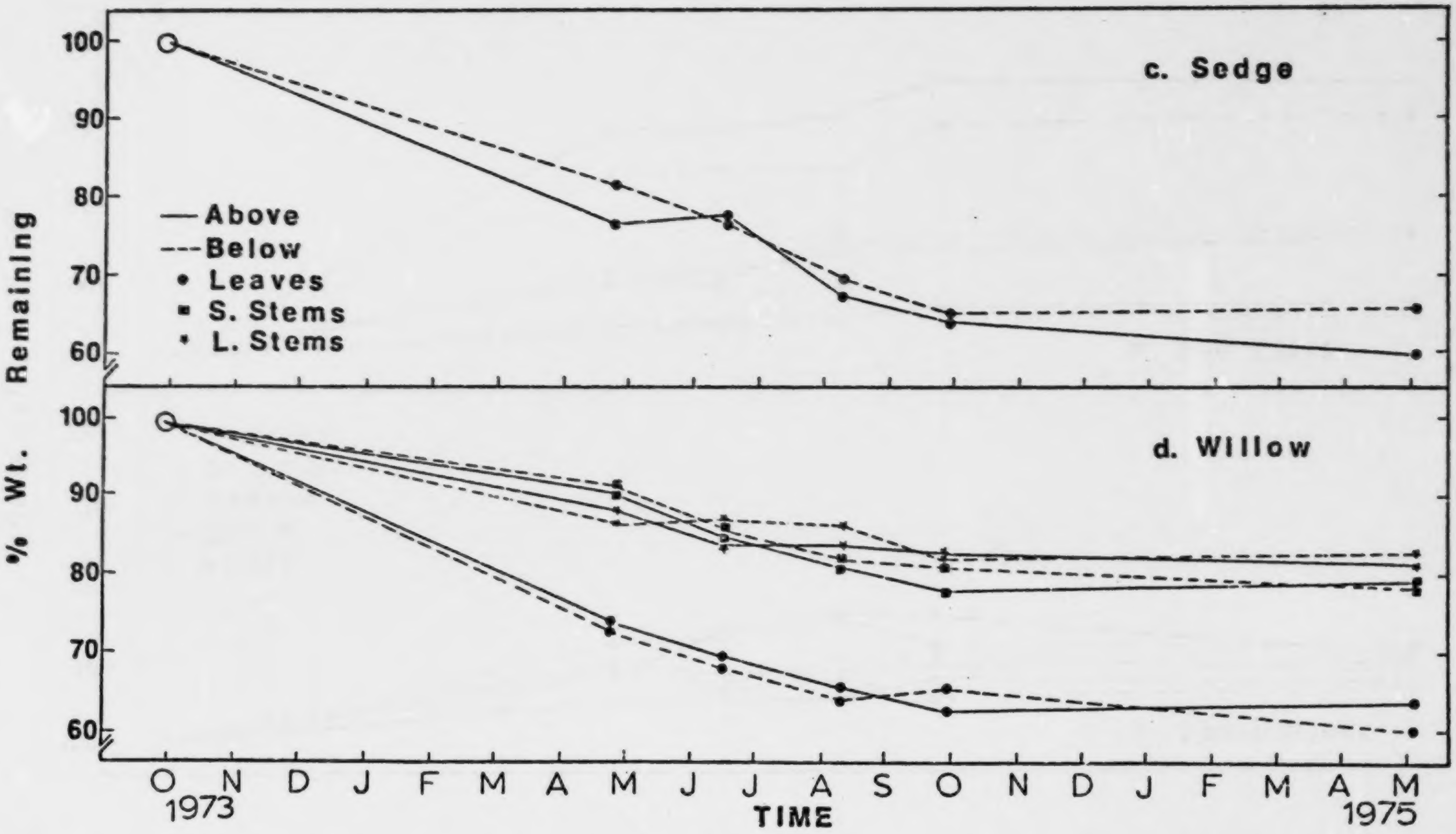


Figure 3.2-5 (concluded). All points repesent a mean of eight samples, except May 1975 which had only four samples. Standard errors about the means never varied more than 13% (leaves of all species), 15% (small stems), and 20% (large stems) (from Chamie 1976).

into the bog by means of the effluent. Mudroch and Capobianco (1979) reported that floating and submerged wetland plants in an Ontario marsh accumulated larger amounts of Pb, Zn, Cr, and Cd than the emergent Glyceria maxima in a marsh receiving poorly treated effluent. Duckweed (Lemna minor) exhibited the highest rates of metal uptake of all plants studied. Because levels of metals in the water were low (less than 1×10^{-3} to 90×10^{-3} mg/l), it was assumed that the sediments were the primary source of these materials (based on chemical analysis of sediment samples). Seidel (1976) reported that uptake of Cn, Co, Mn, Cr, Ni, and V by Scirpus lacustris growing in a sewage pond was 50 times that in a "non-polluted" lake. Uptake of heavy metals by duckweed in cypress domes receiving treated effluent also was shown to occur (Fritz and Helle 1978). Both the Wisconsin DNR (unpublished) and the U.S. Fish and Wildlife Service (in preparation) are currently studying levels of trace metals in Brillion Marsh, Wisconsin, which receives treated effluent from municipal and industrial sources. The results of the USFWS study have shown that levels of trace metals in sediments, water, and animals (ducks, duck eggs, muskrat) were usually at or below typical background levels for the midwest. The results of the WDNR study were similar (until these studies are finalized, no result, can be presented in this review).

Removal of trace metals by vegetation could also have other potential impacts. For example, concentration of trace metals in vegetation could result in a release of toxic materials into the environment as a "slug" once the vegetation dies and enters the detrital breakdown phase (Stanley Consultants 1977). Careful monitoring of trace metal concentrations of organisms in wetlands receiving wastewater would have to be conducted in order to identify these potential impacts.

3.2.2 Effects on Benthic Invertebrate Communities

Wetland ecosystems are characterized by abundant and diverse populations of invertebrates, including protozoa, sponges, coelenterates, flatworms, rotifers, annelid worms, nematodes, amphipods, cladocerans, copepods, other crustaceans, mollusks, and various insect groups (Weller 1978). A summary of the major invertebrate groups that occur in wetlands and their known or suspected ecological roles is provided in Table 3.1-10. Typical densities of

Table 3.1-10. Summary of types of invertebrates known to inhabit wetland habitats in abundance, and their ecological functions (compiled from information in Weller 1978).

Taxonomic Group	Ecological Habitat or Function	Reference in Weller (1978)
I. Protozoans Sponges Coelenterates Flatworms Rotifers Nematodes	● Suspected "vital" but little known functions	Weller 1978
II. Annelids	● Oligochaetes most common annelids; burrowing forms	Erman and Erman 1975 Bergman et al. 1977 Wharton et al. 1977
III. Crustaceans	● May utilize algae and/or detritus	Weller 1978
A. Amphipods/Isopods	● Dense submerged vegetation	Rosine 1955 Krull 1970 Martian and Benke 1977
B. Cladocerans	● May inhabit submerged vascular plants or be free-swimming or limnetic	Quade 1969 Weller 1979
C. Ostracods	● Usually populate benthic sediments	Weller 1978
D. Copepods and Anastracods	● Very abundant; important food for fish and birds	Weller 1978
E. Crayfish	● Inhabit wet meadows, shallow water ● Important in diet of mink, raccoon, and northern pike ● Important in energy transfer via omnivorous activities ● Fed on by snakes, alligators, and fish	Errington 1943 Harris 1952 Lagler 1956 Momot et al. 1978 Lorman and Magnuson 1979 Penn 1950 Penn 1950 Neill 1951

Table 3.1-10. Summary of types of invertebrates known to inhabit wetland habitats in abundance, and their ecological functions (compiled from information in Weller 1978) (concluded).

Taxonomic Group	Ecological Habitat or Function	Reference in Weller (1978)
F. Insects	• Fed on by birds and fish	Weller 1978
1. Chironomids	• Occur in Iowa marshes, California fens, submerged Great Lakes marshes, swamps in Mississippi Basin	Voigts 1976 Erman and Erman 1975 Krecker 1939 Wharton et al. 1977
2. Mayflies		Weller 1978
3. Dragonflies; Damselflies	• Needham and Needham 1941	
4. Stoneflies		Kendeigh 1961
5. Caddisflies	• Variety of habitats and trophic types	Pennak 1978
6. Coleoptera (beetles)		
7. Diptera (flies)		
IV. Mollusks	• Wet meadow to deep water	Baker 1910
A. Gastropods (snails)	• Favored food of larger animals	
B. Pelecypods (clams)		
Sphaerium sp.	• Important food for fish and diving ducks	Ranthum 1969 Thompson 1973
C. Pelecypods (mussels)	• Food of muskrats, mink, otter, raccoon, turtles, and salamanders • Mollusks are good good indicators of chemical pollution	Pennak 1978

aquatic invertebrates by wetland type are given in Tilton and Schwegler (1978). On a seasonal basis, populations of wetland invertebrates generally have much higher diversity and abundance than nearby unvegetated areas (McKim 1962) on a seasonal basis (Voights 1976) (Figure 3.2-6). The invertebrate populations of wetlands are believed to play a central role in the transfer of energy through detrital, photosynthetic, or predatory portions of the food chain (Weller 1979, Swanson 1978a, 1978b). This is especially true of crustaceans, and of crayfish in particular. Invertebrates may play a central role in the transfer of materials between the water and sediment compartments.

Gallepp (1979) reported that in laboratory studies, increasing temperature of lake sediments that contained two species of chironomids from 10°C to 20°C was followed by a ten-fold increase in phosphorus release rates. No change was observed in sediments without chironomids. Graneli (1979 in Nalepa and Quigley 1980) observed that the introduction of chironomid larvae into sediments of eutrophic lakes greatly increased the transport of silica, phosphorus, and iron from the sediments to the water, but did not affect the rate of transfer of inorganic nitrogen.

3.2.2.1 Changes in Benthic Invertebrate Populations

Application of wastewater to a wetland ecosystem could cause several impacts on resident invertebrate populations. These impacts potentially include the following:

- Changes in structure and function of resident invertebrate populations, leading in turn to changes in higher trophic levels;
- Contamination of the wetland food chain by trace metals and/or chlorine and chlorinated hydrocarbons; and
- Transmittal of viral or bacterial diseases through invertebrates to higher food chain organisms, such as birds, mammals (including man), or fish.

Changes in invertebrate population structure potentially could be caused directly by reduction of dissolved oxygen levels due to elevated Biological Oxygen Demand, introduction of elevated amounts of sediment, introduction of toxic compounds, or secondarily by changes in vegetation composition. These changes could include reductions in abundance and diversity or shifts to more

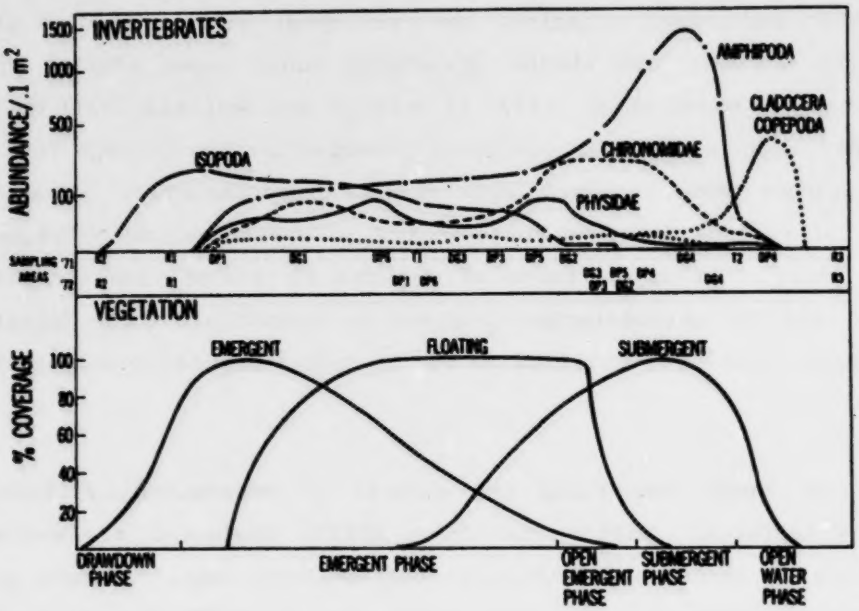


Figure 3.2-6. Model of vegetation and invertebrate changes in a prairie emergent vegetation (from Voights 1976).

"tolerant" types of benthic organisms. Such changes would alter the structure of the wetland invertebrate communities. Direct accumulation of toxic substances within individual organisms and subsequent bioaccumulation of these substances in wetland food chains presumably could cause similar types of community change. Macek et al. (1977 in Buikema and Benfield 1977) determined that for many organic chemical residues, biomagnification through food chains was insignificant when compared with direct bioaccumulation by organisms. Introducton of various diseases could result in contamination of higher food chain organisms. The major types of impacts on benthic macroinvertebrate communities, and the methodologies proposed to investigate these impacts, are shown in Figure 3.2-7 and outlined in the Technical Support Document, respectively.

Little is known concerning the effects of wastewater application on wetland invertebrates. Witter and Crosm (1976) conducted a pre-discharge baseline study on insect populations at the Houghton Lake, Michigan site. A follow-up insect study is currenting being planned at Houghton Lake, but no other similar studies have yet been conducted. Demgen (n.d.) summarized the results of studies of aquatic invertebrate populations in a California wetland receiving treated wastewater (zooplankton also were included in this study). She reported shifts in abundance of major invertebrate species as a result of the added wastewater, but indicated that the new populations appeared to be "stable." Reduced water quality could also alter the structure and function of wetland insect populations. For example, chironomids, species toleratant of low oxygen levels and higher levels of various pollutants, could increase, reducing the diversity of aquatic insect populations. Shifts in insect population structure could also affect detrital decomposition rates of internal detrital recycling, since aquatic insects are important in the initial stages of size reduction of larger plant material to smaller particles (i.e., the shredding process).

3.2.2.2 Changes in Insect Populations

Addition of secondarily treated wastewater to wetlands potentially could alter the structure of resident insect populations (Figure 3.2-8) (methods for assessing impacts on insects are given in the Technical Support Document). For example, a shift in the composition of vascular plant species could favor some

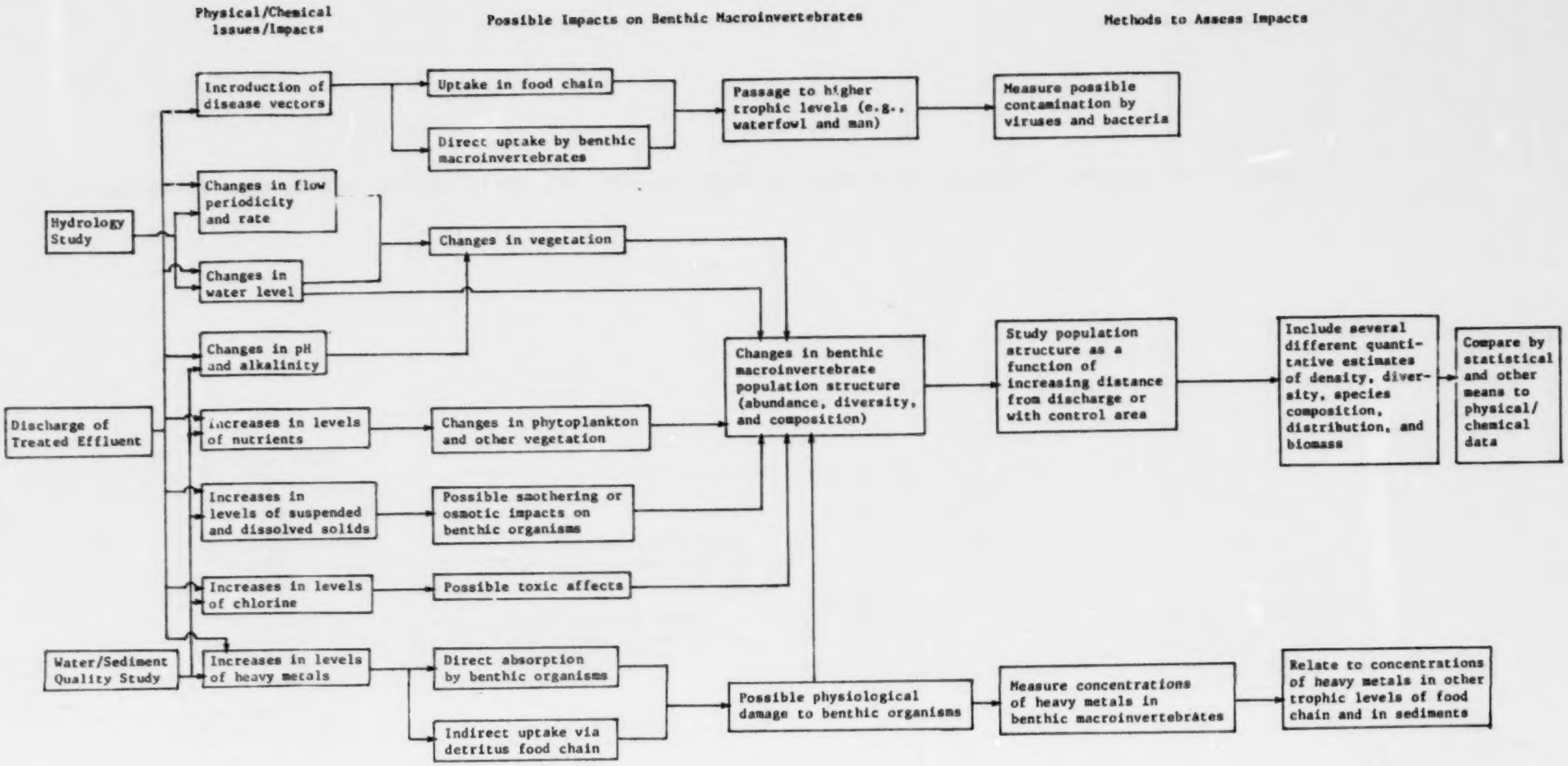

Physical/Chemical Issues/Impacts
Possible Impacts on Benthic Macroinvertebrates
Methods to Assess Impacts
Hydrology Study
Discharge of Treated Effluent
Water/Sediment Quality Study
Introduction of disease vectors
Changes in flow periodicity and rate
Changes in water level
Changes in pH and alkalinity
Increases in levels of nutrients
Increases in levels of suspended and dissolved solids
Increases in levels of chlorine
Increases in levels of heavy metals
Uptake in food chain
Direct uptake by benthic macroinvertebrates
Changes in vegetation
Changes in phytoplankton and other vegetation
Possible smothering or osmotic impacts on benthic organisms
Possible toxic affects
Direct absorption by benthic organisms
Indirect uptake via detritus food chain
Passage to higher trophic levels (e.g., waterfowl and man)
Changes in benthic macroinvertebrate population structure (abundance, diversity, and composition)
Possible physiological damage to benthic organisms
Measure possible contamination by viruses and bacteria
Study population structure as a function of increasing distance from discharge or with control area
Include several different quantitative estimates of density, diversity, species composition, distribution, and biomass
Compare by statistical and other means to physical/chemical data
Measure concentrations of heavy metals in benthic macroinvertebrates
Relate to concentrations of heavy metals in other trophic levels of food chain and in sediments

Figure 3.2-7 Impact factor train for macroinvertebrates (figure created by S.D.Bach, WAPORA, Inc., 1983).

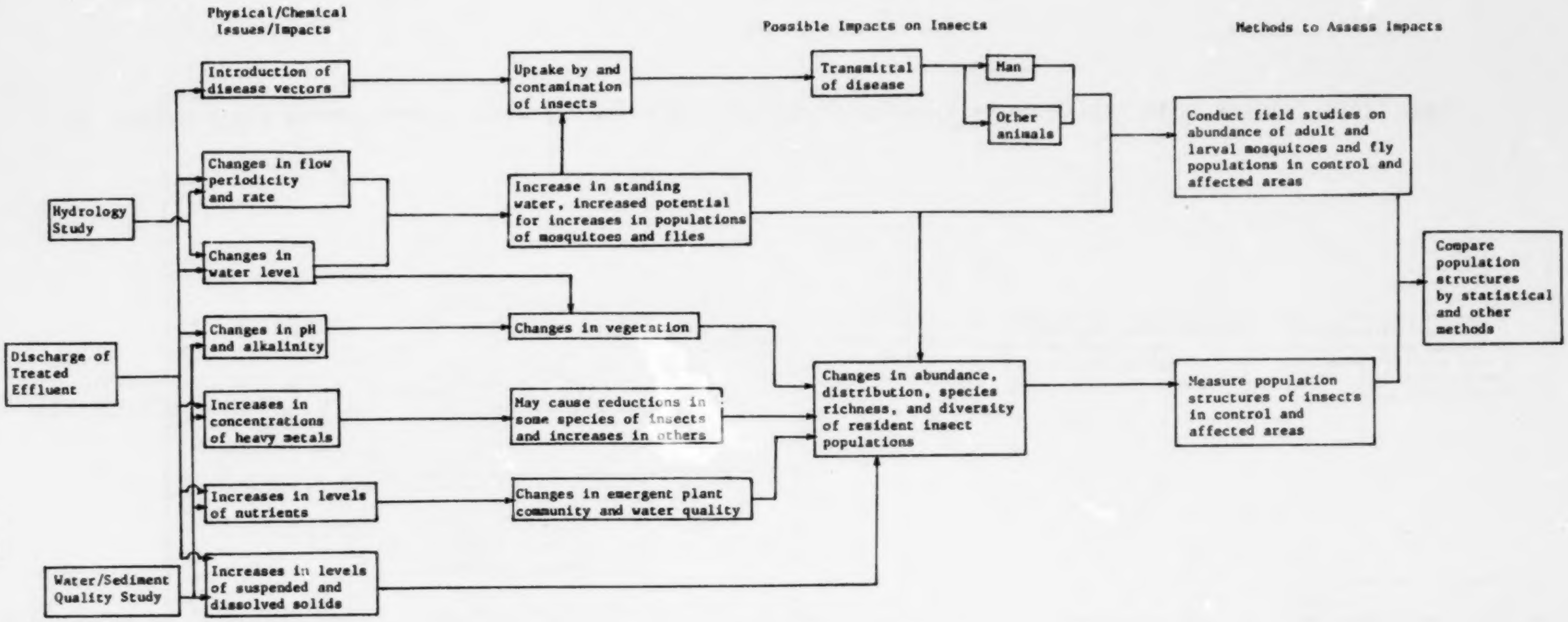

Physical/Chemical Issues/Impacts
Possible Impacts on Insects
Methods to Assess Impacts
Hydrology Study
Discharge of Treated Effluent
Water/Sediment Quality Study
Introduction of disease vectors
Changes in flow periodicity and rate
Changes in water level
Changes in pH and alkalinity
Increases in concentrations of heavy metals
Increases in levels of nutrients
Increases in levels of suspended and dissolved solids
Uptake by and contamination of insects
Increase in standing water, increased potential for increases in populations of mosquitoes and flies
Changes in vegetation
May cause reductions in some species of insects and increases in others
Changes in emergent plant community and water quality
Transmittal of disease
Man
Other animals
Changes in abundance, distribution, species richness, and diversity of resident insect populations
Conduct field studies on abundance of adult and larval mosquitoes and fly populations in control and affected areas
Measure population structures of insects in control and affected areas
Compare population structures by statistical and other methods

Figure 3.2-8. Impact factor train for insects (figure created by S.D.Bach, WAPORA Inc., 1983).

species that inhabit terrestrial environments over others. If the loading rate is sufficient and dissolved oxygen levels are lowered, changes in aquatic insect populations would be expected. One change that could occur includes possible increases in insects that carry diseases that could be transmitted either to man or wildlife. Fritz and Helle (1978) reported that encephalitis-carrying mosquitoes may breed within cypress domes receiving treated wastewater, but that these same species bite birds and avoid areas inhabited by humans. Other varieties of "human pest mosquitoes" were reduced in numbers in cypress domes receiving treated wastewater because the water level did not fluctuate, and thus their breeding grounds were eliminated (Fritz and Helle 1978). Surtees (1971), and Harmston and Ogden (1976) discussed mosquito-related problems associated with urbanization (including sewage stabilization ponds) and man-made impoundments. Also, wild birds are known to be primary carriers of various encephalitis viruses (including St. Louis encephalitis, Eastern equine encephalitis, and Western equine encephalitis), and some mosquitoes may transmit these to birds directly or indirectly through a mammalian overwintering host (Witter and Croson 1976). Mosquitoes also may pass the virus from birds to man (McLintock and Iverson 1974; Hess et al. 1970).

Little is known concerning insect populations in natural freshwater wetlands, and even less is known about these populations in wetlands receiving treated wastewater (Witter and Croson 1976). For example, the only recent studies of freshwater insects in wetlands include those of Judd (1949, 1953, 1960, 1961), Jetter (1974, 1975), and Witter and Croson (1976). Jetter (1975) reported that certain species of dipteran flies, including members of the families Psychodidae, Ephydridae, Tipulidae, Dolichopodidae, and Syrphidae, were very abundant (densities of over 3,000 individuals per square meter) on mats of floating organic material produced when treated wastewater was added to a cypress dome in Florida. When the amount of sewage being discharged was decreased, the numbers of these same groups declined drastically. Witter and Croson (1976) reported that sampling methods used to collect insects are highly variable and may yield biased results in many cases. This makes studies of insects in wetlands difficult.

3.2.3 Effects on Fish Communities

The major types of impacts on fish communities that potentially could be caused by the application of wastewater are shown in Figure 3.2-9. Available methodologies to assess these impacts are summarized in the Technical Support Document. The major types of impacts are:

- Changes in species composition;
- Changes in productivity or biomass;
- Changes in spawning success;
- Toxicity (acute, chronic, or sublethal); and
- Changes in incidence of disease in fish or in the potential for fish acting as vectors for mammalian pathogens.

It is acknowledged that wetlands are available to fish as permanent habitat, spawning habitat, and for the production of forage. However, quantitative data to support this widely-held assumption are lacking. In one of the few available studies, Jaworski and Raphael (1978) reported that at least 32 species of fish commonly use the wetlands in Michigan. Many of these use the wetlands for spawning. There are several reasons for the general lack of data on wetland fish. Wetlands are by their nature highly dynamic systems, and are usually hydrologically connected to other water bodies. These two characteristics make quantitative measurements extremely difficult. The logistical difficulties of sampling wetlands also have prevented fish studies from being undertaken.

Literature specifically describing the impacts of wastewater effluents on fishes in wetlands is nearly nonexistent. In one of the few studies of wetlands that did address fish communities (Jetter and Harris 1976), researchers reported that a cypress dome in Florida receiving sewage effluent was a much poorer habitat for fish than a natural cypress dome. In contrast, a great deal of information is available regarding the general impacts on fish communities caused by the discharge of wastewater into streams and lakes. This information is reviewed in sources such as Tsai (1975), Brungs et al. (1978),

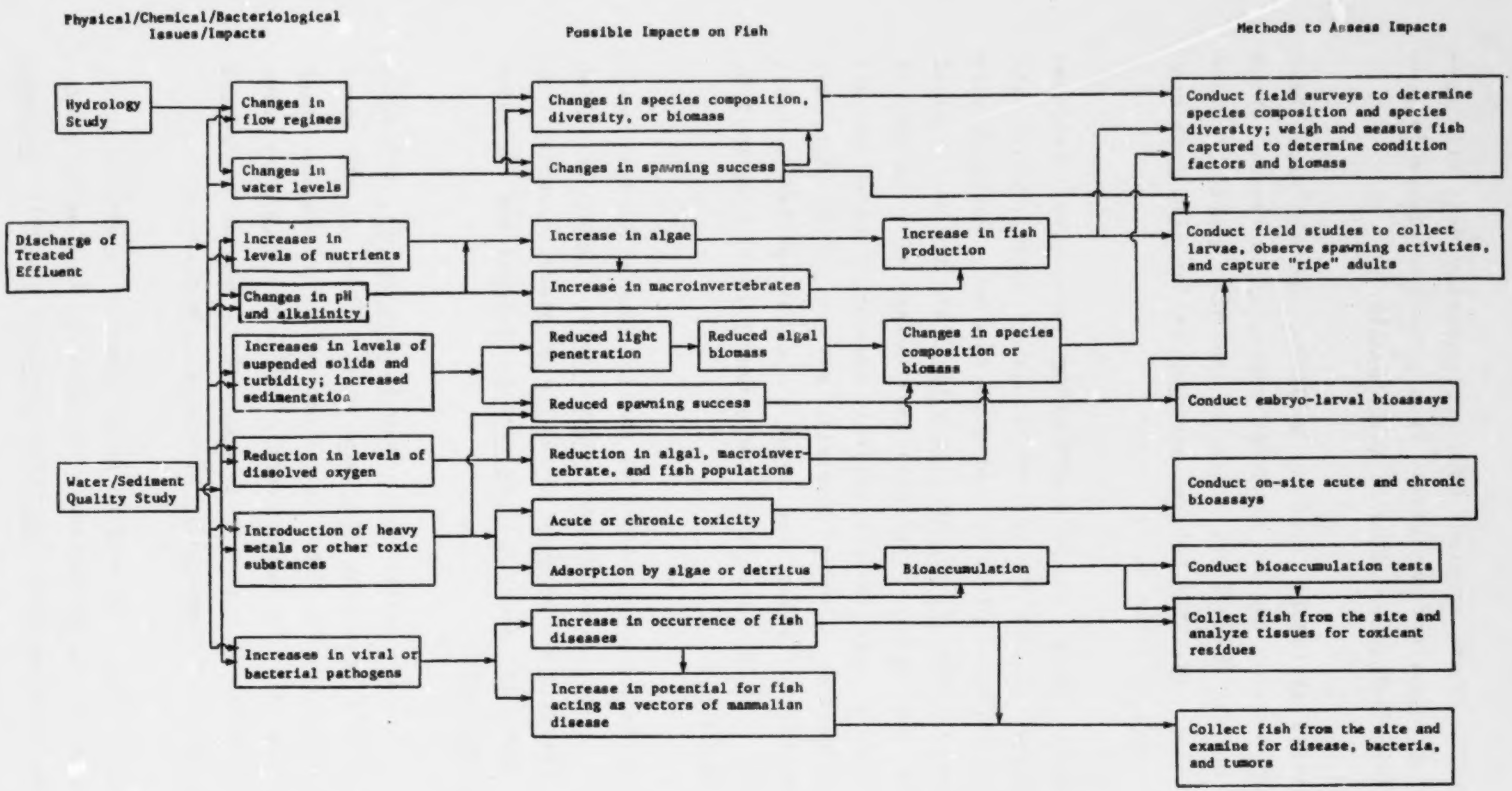

Physical/Chemical/Bacteriological Issues/Impacts
Possible Impacts on Fish
Methods to Assess Impacts
Hydrology Study
Discharge of Treated Effluent
Water/Sediment Quality Study
Changes in flow regimes
Changes in water levels
Increases in levels of nutrients
Changes in pH and alkalinity
Increases in levels of suspended solids and turbidity; increased sedimentation
Reduction in levels of dissolved oxygen
Introduction of heavy metals or other toxic substances
Increases in viral or bacterial pathogens
Changes in species composition, diversity, or biomass
Changes in spawning success
Increase in algae
Increase in macroinvertebrates
Reduced light penetration
Reduced algal biomass
Reduced spawning success
Reduction in algal, macroinvertebrate, and fish populations
Acute or chronic toxicity
Adsorption by algae or detritus
Increase in occurrence of fish diseases
Increase in potential for fish acting as vectors of mammalian disease
Increase in fish production
Changes in species composition or biomass
Bioaccumulation
Conduct field surveys to determine species composition and species diversity; weigh and measure fish captured to determine condition factors and biomass
Conduct field studies to collect larvae, observe spawning activities, and capture "ripe" adults
Conduct embryo-larval bioassays
Conduct on-site acute and chronic bioassays
Conduct bioaccumulation tests
Collect fish from the site and analyze tissues for toxicant residues
Collect fish from the site and examine for disease, bacteria, and tumors

Figure 3.2-9 Impact factor train for fish (figure created by G. Seegart, WAPORA, Inc., 1983).

and Spehar et al. (1980). These studies, however, generally deal with discharges into lakes and streams, not wetlands. Thus their usefulness in predicting impacts on wetland fish communities is questionable.

The basic fish communities typically found in wetlands, and the ways these communities utilize the wetland, can be described generally, however. Three types of fish communities can be defined. These include the "general," "forage," and "spawning" types. Expected habitat preferences for each fish community in wetlands are given in Table 3.2-1.

The "general" community type is a self-sustaining, usually well-balanced community that lives in and utilizes the wetland throughout each species' life cycle. This community includes predator and prey species. Northern pike (*Esox lucius*) and largemouth bass (*Micropterus salmoides*) are the most typical predatory species. The prey species typically is composed of a variety of minnows. The wetland itself must contain suitable spawning habitat for all the members of the community. Species diversity may be fairly high, but because of the stresses on the system, the total number of species probably will be low. Obviously, only wetlands that are permanently flooded will be able to support such communities.

The forage community is composed mainly of smaller (and often more tolerant) species such as: central mudminnow (*Umbra limi*); banded killifish (*Fundulus diaphanus*); blackstripe topminnow (*Fundulus notatus*); mosquito fish (*Gambusia affinis*); ninespine stickleback (*Pungitius pungitius*); and fivespine stickleback (*Eucalia inconstans*).

Minnows, such as the golden shiner (*Notemigonus crysoleucas*), are often present, as well as various sunfishes (*Lepomis* spp.). Many of the above species are adapted to drought conditions, low dissolved oxygen levels, high temperatures, and turbid waters. The more severely stressed communities often are composed of only one or two species. These communities provide forage for various wetland mammals and birds, especially herons and kingfishers.

The spawning community occurs in wetland areas that are regularly, or at least occasionally, flooded in the springtime. Wetlands may be used as spawning grounds for species such as carp (*Cyprinus carpio*), bluegill (*Lepomis*

Table 3.2-1. Expected use of various types of freshwater wetlands by different types of fish communities (Seegart, unpublished).

Water Regime	General	Forage Only	Spawning	None
Permanently flooded	●		●	
Intermittently exposed	●		●	
Semi-permanently flooded		●	●	
Seasonally flooded		●	●	
Saturated				●
Temporarily flooded				●
Intermittently flooded				●

macrochirus), crappie (*Pomoxis* spp.), and predators such as northern and walleye pike. Certain wetlands adjacent to the Wolf River system and Fox River system in central Wisconsin, for example, are important spawning areas for walleye (*Stizostedion vitreum*). The importance of these wetlands as spawning and nursery areas varies greatly from year to year. During dry years, they may not be accessible at all, or may dry up too quickly following spawning, thereby killing the eggs or larvae. However, during wet years they may be important contributors to the fish communities present in the adjacent lakes and rivers.

3.2.4 Effects on Wildlife Communities

The use of wetlands by wildlife is dependent on the ability of the natural system to provide the necessary food, shelter, protection from predators, and appropriate areas for breeding, nesting, and other events in the activity and population cycles of each species. Thus, the number of species and individuals present at any time are dependent on the availability of wetland habitat and the population levels of the species in the region (including migratory species).

Severe or unfavorable weather conditions, heavy predation losses, or population cycles may cause changes in the abundance of species from year to year that are not related to the characteristics and condition of the wetland. The changes in the wildlife community at a wetland receiving effluent may result from changes in water level, the structure and composition of the vegetation, the interspersion of vegetation and water (an important determination of species richness) (Figure 3.2-10), as well as the availability of submerged plants, aquatic and terrestrial insects, and other sources of food. Changes in the number and abundance of adults and young of prey species such as amphibians, small birds, and small mammals will result in changes in the number and abundance of carnivorous species of birds and mammals that constitute the higher trophic levels.

The changes in water levels associated with the introduction of treated wastewater also would be expected to result in shifts of the locations of wildlife breeding and activity sites within the wetland and between the wetland and adjacent wetland or upland areas. This is because different wildlife species occupy or exploit different ecological zones of most wetlands (Figure 3.2-11). Water-level changes also will influence the types and amounts of food organisms present, and the wastewater entering the wetland may contain pathogenic organisms and trace metals that can be taken up directly by individual wildlife or indirectly through the organisms on which they feed. The general types of impacts on wildlife that may occur subsequent to the introduction of treated wastewater to a wetland are indicated in Figure 3.2-12. Available impact assessment methodologies are outlined in the Technical Support Document.

3.2.4.1 Wildlife Use of Treatment Facilities

The roles and habitat requirements of many species of wildlife that use wetlands have been indicated by various authors in Greeson et al. (1979). The open water and undisturbed locations typical of effluent lagoons and stabilization ponds associated with wastewater treatment facilities fulfill some of the requirements of a number of species of wildlife, and are particularly attractive to migratory waterfowl. Other species of wildlife associated with wetlands visit these areas periodically to feed on the plants and/or animals present in or near the water.

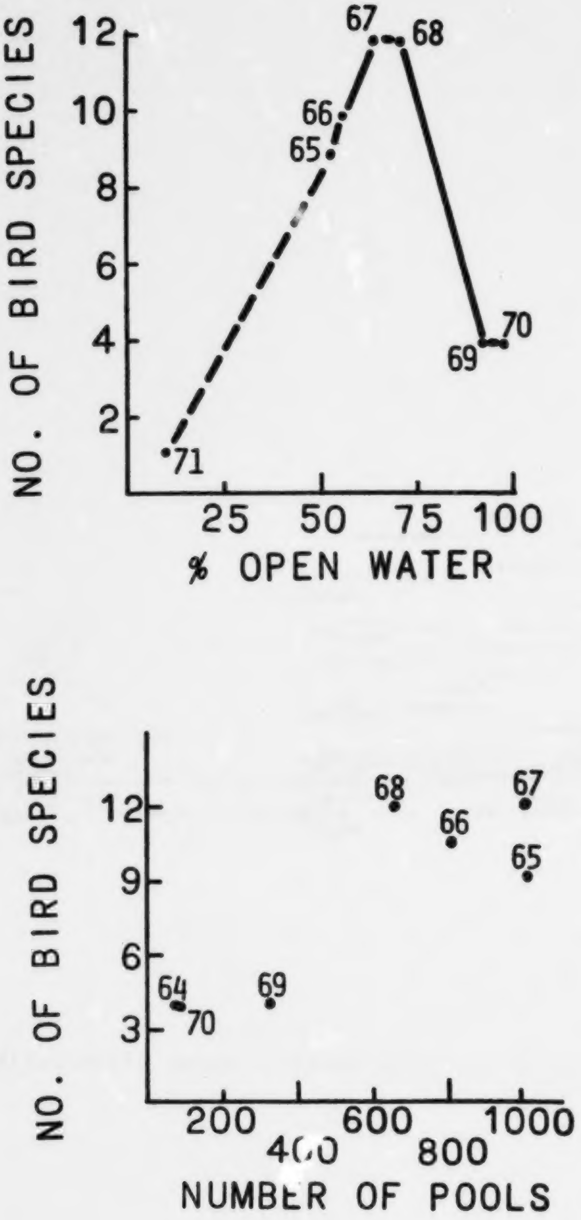


Figure 3.2-10. Species richness as a function of water openings and percent open water (from Weller and Fredrickson 1973).

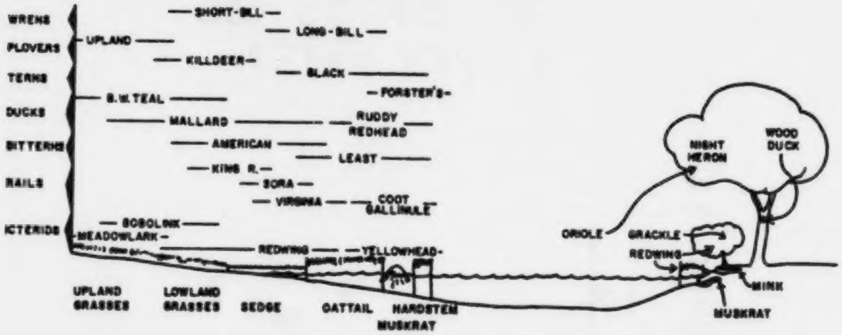

WRENS
PLOVERS
TERNS
DUCKS
BITTERNS
RAILS
ICTERIDS
SHORT-BILL
LONG-BILL
UPLAND
KILLDEER
BLACK
FORSTER'S
B.W. TEAL
MALLARD
RUDDY
REDHEAD
AMERICAN
LEAST
KING R.
SORA
VIRGINIA
COOT
GALLINULE
BOBOLINK
MEADOWLARK
REDWING
YELLOWHEAD
NIGHT HERON
WOOD DUCK
ORIOLE
GRACKLE
REDWING
MINK
MUSKRAT
UPLAND GRASSES
LOWLAND GRASSES
SEDGE
CATTAIL
HARDSTEM
MUSKRAT

Figure 3.2-11. Bisect through a glacial prairie marsh (from Weller and Spatcher 1965).

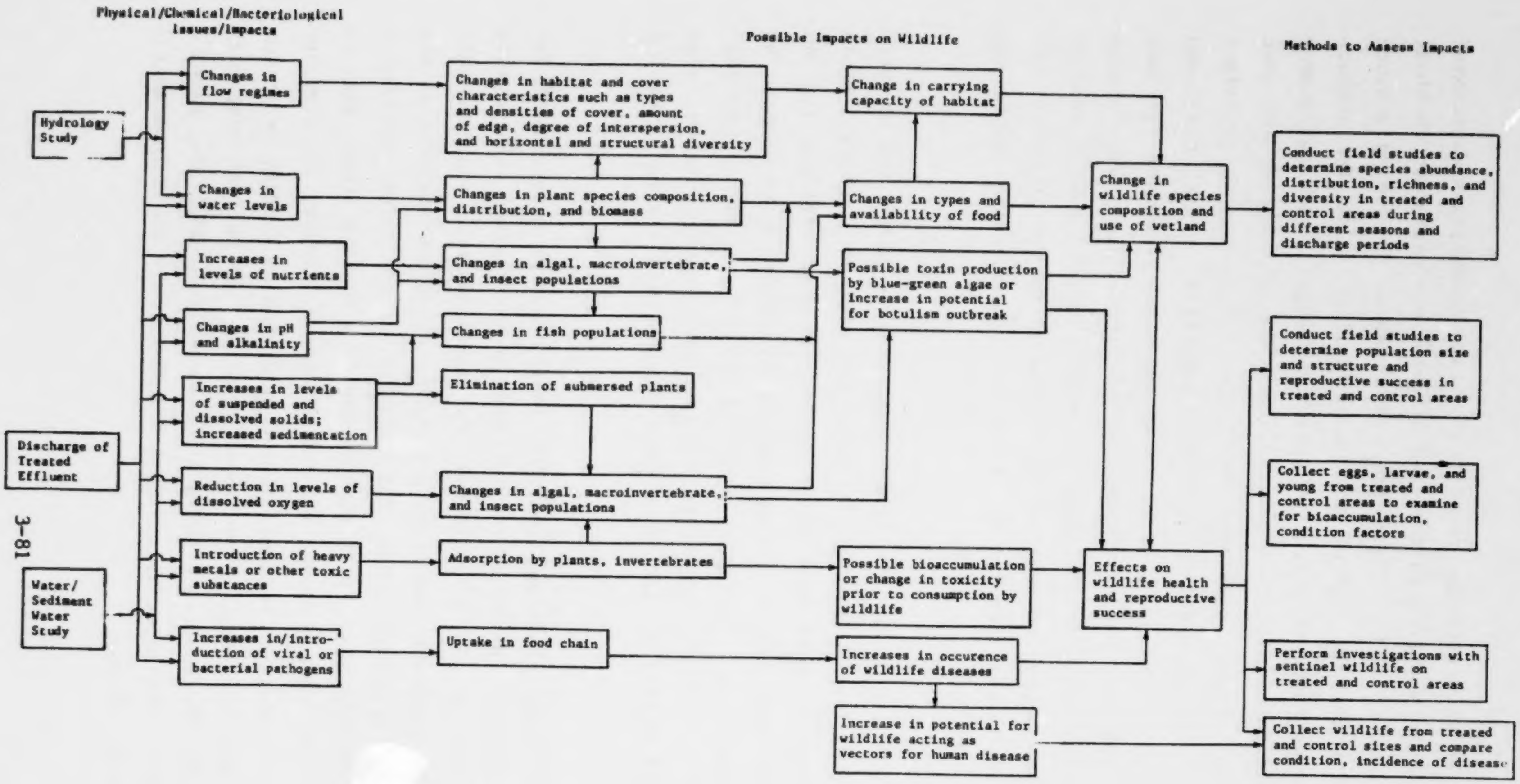

Physical/Chemical/Bacteriological issues/Impacts
Possible Impacts on Wildlife
Methods to Assess Impacts
Hydrology Study
Discharge of Treated Effluent
Water/ Sediment Water Study
Changes in flow regimes
Changes in water levels
Increases in levels of nutrients
Changes in pH and alkalinity
Increases in levels of suspended and dissolved solids; increased sedimentation
Reduction in levels of dissolved oxygen
Introduction of heavy metals or other toxic substances
Increases in/introduction of viral or bacterial pathogens
Changes in habitat and cover characteristics such as types and densities of cover, amount of edge, degree of interspersion, and horizontal and structural diversity
Changes in plant species composition, distribution, and biomass
Changes in algal, macroinvertebrate, and insect populations
Changes in fish populations
Elimination of submersed plants
Changes in algal, macroinvertebrate, and insect populations
Adsorption by plants, invertebrates
Uptake in food chain
Change in carrying capacity of habitat
Changes in types and availability of food
Possible toxin production by blue-green algae or increase in potential for botulism outbreak
Possible bioaccumulation or change in toxicity prior to consumption by wildlife
Increases in occurence of wildlife diseases
Increase in potential for wildlife acting as vectors for human disease
Change in wildlife species composition and use of wetland
Effects on wildlife health and reproductive success
Conduct field studies to determine species abundance, distribution, richness, and diversity in treated and control areas during different seasons and discharge periods
Conduct field studies to determine population size and structure and reproductive success in treated and control areas
Collect eggs, larvae, and young from treated and control areas to examine for bioaccumulation, condition factors
Perform investigations with sentinel wildlife on treated and control areas
Collect wildlife from treated and control sites and compare condition, incidence of disease

Figure 3.2-12. Impact factor train for wildlife (figure created by K. Brennan, WAPORA, Inc., 1983).

The only study known concerning the types of bird communities associated with different methods of sewage treatment and disposal was performed in Great Britain (Fuller and Glue 1980). This study is a review of the literature including census data on bird use of treatment facility sites The authors categorized the species observed into four seasonal groups: breeding, summer feeding, spring and autumn (migration periods), and winter. Fuller and Glue (1980) concluded that sewage treatment facilities can serve as important feeding sites for passerine species, primarily songbirds, and that systems with percolating filters and land application types of treatment (surface irrigation) support the most varied communities of birds. Large populations of waterfowl and wading birds were present at "sewage farms" formerly used as treatment sites. The species composition was dependent on the quality of the emergent and bankside vegetation on the sides of the irrigation plots and lagoons.

Fuller and Glue (1980) reported that insect-eating birds fed on prey items within the percolating filters and/or above the effluent lagoons. Birds of prey were observed to hunt over these areas. Drained effluent lagoons attracted shorebirds, and shallow filled lagoons attracted large numbers of wading birds, especially if bordered by areas of unvegetated mud. Many passerine species fed on insects in sludge drying beds. Sludge lagoons also served as sources of seeds, as did uncultivated areas and the banks of the lagoons.

The variety of birds visiting treatment facilities to obtain food decreased during the winter, but increased at times in correlation with adverse weather conditions (Fuller and Glue 1980). The total number of individuals was highest in winter, and many waterfowl and wading birds overwintered in the lagoons. The authors concluded that the outdated sewage farms provided a large amount of wetland habitat, with both feeding and nesting areas, that is not present in the more modern sewage treatment works. However, the development of percolating filters has resulted in the provision of feeding areas for passerine species, and land application areas provide some habitat that partially compensates for the adverse effects of development on wildlife, particularly in urban areas. The majority of these facilities are small in comparison to the older sewage farms.

In the United States, a number of short-term studies have been conducted on waterfowl use of wastewater lagoons and oxidation ponds (Dornbush and Anderson 1964; Willson 1975; Dodge and Low 1972). Swanson (1977) studied the feeding behavior and food items consumed by adult and immature surface-feeding ducks on stabilization ponds in North Dakota. The birds fed primarily on immature midges and water fleas during the day, adult insects during the evening, and water fleas between midnight and sunrise. Pairs and broods of mallards and gadwalls were the most frequently observed ducks on the ponds. Swanson (1977) suggested that upland nesting cover be improved and that pond shorelines be designed to reduce the likelihood of disease in order to make the ponds safer and more valuable to waterfowl. He also recommended that the potential for heavy metal uptake and concentration in the food chain and for increased incidence of disease at the ponds be investigated before such habitat enhancement be performed.

3.2.4.2 Effects of Wastewater Application on Wildlife at Land Treatment Sites

Estimates of the effects of wastewater application on terrestrial wetland animals may be inferred from the results of studies conducted by Anthony and Wood (1979), Anthony et al. (1979), Bierei et al. (1975), Lewis (1978), and Snider and Wood (1975). They noted the following results:

- Forage production for deer was lower during the summer, and the levels of protein, phosphorus, potassium, and magnesium in the forage species increased, while calcium levels were reduced;
- Increased soil moisture content enhanced the production of herbaceous plants dramatically, but plant species diversity declined; many of the species that increased in biomass were unpalatable to wildlife, and the net effect was a reduction in the amount of available forage; and
- Levels of chromium were significantly higher, and levels of nickel significantly lower, in tissues of rabbits and mice collected from irrigated areas as compared to control areas.

Levels of copper were higher in kidneys of cottontail rabbits from the control area. However, these studies were short-term investigations on relatively small sample plots, and the investigators recommended that more detailed studies be conducted over longer periods of time. They also reported that different species would accumulate the same heavy metals at different rates due to differences in food habits (species of plants or animals consumed, parts of these organisms consumed, etc.), and that these rates also would vary at times within a species because of seasonal differences in food availability.

3.2.4.3 Effects of Wastewater Application on Wildlife in Wetlands

The most detailed studies of changes in animal species composition and biomass have been performed on cypress domes in Florida (Ramsay 1978; Jetter & Harris 1976). They conducted baseline and experimental studies on the amphibian, avian, and mammalian populations in treated and control domes, and correlated the changes in wildlife populations in the treated dome primarily with changes in the water level, water quality, and invertebrate abundance. The number and diversity of bird species increased significantly in the treated dome (Ramsay 1978), and aquatic mammals were observed there that were not present in the control dome (Jetter and Harris 1976). The number of amphibians increased significantly in the treated dome as animals came there to breed because of the higher water level (and greater food availability). The treated dome attracted small amphibians from adjacent forested areas, but reproduction was not successful due to the poor water quality. The treated dome provided a beneficial function for amphibians during drought periods, since it served as a reservoir for reestablishment of populations in forested areas and in other domes after fires had destroyed those habitats.

An accidental release of sludge into the treated dome resulted in the formation of a mat of organic debris and the subsequent development of anaerobic conditions. These conditions were favorable to organisms that could not tolerate anoxic conditions and resulted in a major shift in the species composition of wildlife in the dome (Jetter and Harris 1976). The top consumers in untreated control domes (primarily wading birds such as herons and egrets) were eliminated from the treated dome because the organisms on which they fed (aquatic insects, crayfish, and fish) could not survive. The number of species of insect-eating songbirds increased significantly.

Within the Region V states, investigations on wildlife populations in wetlands receiving wastewater have been performed at two natural sites (Houghton Lake, Michigan, and Drummond, Wisconsin) and two volunteer wetlands (Vermontville, Michigan, and Paw Paw, Michigan). It is expected that a number of the effects on wildlife populations that may occur will be detectable only after changes in the vegetation and other components of the habitat have occurred. The length of time required for these changes is not known, but it is likely to differ greatly between each site.

Kadlec (1979) reported that there were no major shifts in species abundance or species composition of bird populations at the Houghton Lake, Michigan treatment site from 1975 to 1977, nor were there any observable adverse effects on mammal populations in the area. A significant increase in muskrat populations occurred due to increase cattail abundance. A minor increase in meadow voles also occurred in the vicinity of the discharge due to increase availability of grasses.

Anderson and Kent (1979) described amphibian, reptile, bird, and mammal studies conducted at the Drummond, Wisconsin site. Pre-treatment studies were performed on the portion of the bog used as the treatment site, the control site, a stream flowing from the bog, the lake into which the stream flows, and the surrounding upland areas. Post-treatment studies were performed for four months after initiation of the discharge. The raw data on the species collected were presented in Anderson and Kent (1979), but no analyses accompanied this information.

Bevis (1979) studied wildlife at the Vermontville and Paw Paw, Michigan sites. At Vermontville, volunteer wetlands were created by the wastewater discharges, and provided habitat for wildlife in the area. Redwing blackbird, coot, and goldfinch nested in the newly created marsh and bluewinged teal and mallards used the wetland as a feeding or resting stop during migration. The wetland also provided habitat for numerous amphibians and reptiles (Table 3.2-2). Additional studies need to be performed at these sites before any conclusions can be drawn, however, concerning the possible long-term effects on wildlife. In the short-term (six years), wildlife habitat appears to have been enhanced at these sites.

Table 3.2-2 Summary of occurance of amphibians and reptiles in Vermontville, Michigan, volunteer wetland (from Sutherland and Bevis n.d.).

Species	1	2	3	4	P1	P2
Snapping Turtle, *Chelydra serpentina*		●			●	●
Eastern Painted Turtle, *Chrysemys picta picta*		●			●	●
Eastern Garter Snake, *Tharmophis sirtalis sirtalis*			●	●		
Eastern Milk Snake, *Lampropelitis triangulum triangulum*			●	●		
American Toad, *Bufo americanus*	●	●	●	●		●
Bullfrog, *Rana catesbeiana*						●
Green Frog, *Rana clamitans melanota*	●	●	●	●		●
Northern Leopard Frog, *Rana pipiens*	●	●	●	●		●

The benefits to waterfowl and other species of wildlife resulting from the use of wastewater for habitat enhancement were reported by Cederquist et al. (1979) and Cederquist (1980a, 1980b) for a wastewater discharge to a natural wetland and by Demgen (1979a, 1979b) for a discharge to an construets wetland. These studies are discussed in Section 3.3.

3.2.4.4 Rare, Threatened, and Endangered Species

The role played by wetlands in the preservation of rare, threatened, and endangered species is becoming increasingly important as the number and average size of wetlands diminishes as a consequence of drainage and habitat alteration and adjacent land use activities (Williams and Dodd 1979, Landin 1979). For some species, wetlands are required during only part of the year or during a portion of the life cycle. For example, the bog turtle (*Clemmys muhlenbergi*) and other turtles migrate to wetlands during autumn to hibernate, and one rare species of snake--Kirtland's water snake, *Clonophis kirtlandii*--inhabits wetlands in the Region V states (Williams and Dodd 1979).

No site in the Phase II study should be selected for the application of wastewater if it is known to be inhabited by a species indicated as endangered or threatened on federal or state lists, without the knowledge and permission of the responsible agency. Any plant or animal that is observed at or in the vicinity of a study site and is known to be listed by either federal or state authorities should be reported, and a decision should be made on whether to continue the study. Care should be taken to avoid disturbing threatened or endangered species or their habitats, especially during the breeding season. Friend (1982) suggests that when migratory birds are the endangered or threatened species of concern, effluent discharges into the wetland should be avoided for 30 days after the last known date on which the species was observed.

The data obtained on the presence, abundance, and other population characteristics of endangered, threatened, and rare species observed during the Phase II study should be made available to the local and regional offices of USFWS and the various divisions and offices of the state environmental resource agencies. It is assumed that the state and USFWS personnel responsible for monitoring the study would assist in the distribution of information to the appropriate personnel within their agencies. Besides providing valuable information on the status of these species, the data obtained would be useful in the determination of the potential impacts on such species (both beneficial and adverse) of the construction and operation of wastewater treatment facilities (including natural, artificial, and volunteer wetland treatment sites). In particular, the information obtained during the course of investigations on the potential for enhancement of wildlife habitat should prove valuable in future federal and state agency planning efforts for protected species. For example, Bevis (personal communication) has transplanted specimens of the Michigan iris, a rare species in Michigan, into the volunteer wetland at Vermontville, Michigan to test the potential for the establishment and maintenance of an additional population of that species at the site.

3.3 Issue Category III: Potential for Enhancement of Wildlife Habitat

The availability of a continuous source of water and nutrients associated with a wetland discharge has been suggested as a potential resource for the creation, maintenance, and enhancement of wetland habitats. On the basis of preliminary results obtained at a few sites, however, it appears that the introduction of wastewater to natural wetlands is followed by a decrease in the diversity of species and the decline or disappearance of sensitive species that are intolerant of changes in physical and chemical parameters. This is coupled with an increase in the number and abundance of opportunistic and common species that can adjust to a wider range of conditions and habitats. A number of researchers who have conducted ecological investigations at wastewater discharge sites have recommended that wastewater not be discharged to natural wetlands, that wastewater be discharged only on a carefully controlled experimental basis, or that only discharges to degraded wetlands be allowed, until more information is obtained (Guntenspergen and Stearns 1983; Benforado 1982; Stearns 1978; Sloey 1978). The actual potential for using treated wastewater to enhance pre-existing wetlands may be low because of the likelihood of adverse effects on the wildlife and fish communities. The actual use of wastewater to enhance wetlands may thus be limited to use in previously degraded systems.

3.3.1 Natural Wetlands

The introduction of wastewater into natural wetlands presently used as treatment sites has altered the receiving environment sufficiently that the species composition of the pre-discharge plant and animal communities has changed (i.e. Jetter and Harris 1976; Bevis 1979). However, these systems still retain the basic characteristics of a wetland. The characteristics of this disturbed habitat no longer fulfill the requirements of some species, but the alteration of conditions may result in the increase of other species not previously present in abundance. This phenomenon was documented by Jetter and Harris (1978) for cypress domes in Florida that received treated wastewater and that had been accidentally contaminated with sludge (Section 3.2.4.3).

Wastewater has been used on a seasonal basis, however, for habitat enhancement in coastal marshes (Suisun Marsh in California) for several years without noticeable adverse effects on wildlife populations (Cederquist et al. 1979; Cederquist 1980a, b). One marsh received only wastewater, two received different combinations of wastewater and slough water, and a fourth (control) received only slough water. No problems were noted except for algal blooms during the spring and pond flooding in the autumn. The wastewater is used for irrigation of surrounding agricultural lands during the dry season and for marsh management during waterfowl migration periods.

3.3.2 Constructed Wetlands

The problems associated with dredged spoil disposal have stimulated considerable research in wetland habitat development, primarily in coastal areas. The most comprehensive work has been conducted under the sponsorship of the US Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi (Scots and Landin 1978). This agency coordinated laboratory and field studies on the creation of wetlands at nine coastal or riverine sites during the mid-1970's and also conducted assessments of the environmental impacts of such activities.

Demgen (1979a,b) reported benefits to wildlife populations from the construction of a small wetland in California. This pilot project was initiated in 1974 to demonstrate the feasibility of using secondary effluent for creation of wildlife habitat and to test various techniques for the improvement of water quality and wildlife habitat. A series of five interconnected areas, totaling 8.2 hectares (20.3 acres), was located in a tidal area. Wastewater passed by gravity flow through the system and discharges to a slough that connected to Suisan Bay. The last cell in the fourth plot contains habitat enhancement devices, called ecofloat. These raft-like flotation structures provided resting and breeding areas for waterfowl, and floats for sacks filled with redwood bark that provides substrates for aquatic invertebrates.

One plot was planted with grasses and bulrushes to provide food for migratory waterfowl, and another was maintained as an open-water area with four vegetated islands. The combination of habitat types and the availability of food, cover, and protected nesting sites resulted in intensive use of the site by waterfowl. Small mammal, amphibian, reptile, and fish became established as well. Mosquito fish have been harvested for use in mosquito control efforts by the local mosquito abatement district. Crayfish and other invertebrates could be marketed for bait and as food for tropical fish, if desired.

The educational and recreational benefits provided by the site are also being utilized.

In 1978 the EBC Company began a pilot project that combined marsh and forest habitats for improvement of effluent quality, habitat development, and timber production. The Ecofloats described previously, water-level control devices, paddle-wheel-type aerators, and an underground irrigation system with an infiltration unit under each redwood tree were used as components of this "marsh-forest system" (EBC Company 1979). The system is operating properly and appears to be meeting the desired objectives (Demgen 1979). Small (1976) reported that the small artificial wetlands constructed by researchers at Brookhaven National Laboratory, New Jersey, attracted amphibians, waterfowl, and shorebirds.

Weller (1978) described a constructed marsh where a number of similar units of habitat could be managed experimentally. Such a facility recently was constructed at the Delta Waterfowl Research Station in Manitoba, Canada. The results of investigations at that site will serve as the basis for future developments in management of inland freshwater marshes. However, the results of the first long-term studies to be performed at that site may not be available for several years.

Garbisch (1978) conducted a survey of marsh establishment or restoration projects. Only 18 of 105 completed or ongoing projects were located in or near freshwater locations. The technology of marsh rehabilitation is of recent origin, and has been developed primarily for application to brackish and saltwater areas. Garbisch concluded that general guidelines for marsh development may be helpful, but that these programs should be tailored to the unique characteristics of each site. Garbisch (1978) also reported that the maximum functional level (vegetative and wildlife productivity, water purification, etc.) of created marshes is attained within one to three years, and that these functions appear to be comparable to those of natural wetlands. Information on various techniques for the construction of artificial wetlands is available from the state wildlife agencies in USEPA Region V, in the form of research reports and brochures for landowners, such as that prepared by New (n.d.) of the Indiana Department of Natural Resources.

3.3.3 Volunteer Wetlands

The only work conducted in volunteer wetlands is that of Bevis (1979) and Sutherland and Bevis (n.d.), who studied volunteer wetlands that developed at treatment sites in Vermontville, Michigan, and Paw Paw, Michigan. Bevis (1975) noted that such areas could serve as refuges for rare species of plants and animals. Some species, particularly plants, could be transplanted or stocked at those locations. The access limitations and present use of the sites would limit their use by the general public for recreational or harvest purposes, although scientific studies would be possible.

The potential for the development of volunteer wetland vegetation as a result of wastewater discharge in USEPA Region V appears to be high, given the general climatic and soil conditions and the previous history of wetlands in many parts of the region. As previously indicated. it is likely that a number of these sites presently exist in association with wastewater treatment facilities, and several potential study sites may be identified in addition to those investigated by Bevis (1979).

3.4 Issue Category IV: Health/Disease Considerations

3.4.1. Effects on Human Health

Human pathogens do survive wastewater treatment. However, their density generally decreases as a result of the process. Grimes (1982) concluded that once pathogens and fecal indicators are released to the water column, they do not always die, but may become non-culturable and settle into the bottom sediments. This may render the pathogens undetectable by conventional culturing techniques used to assess the safety of water.

An overview of the literature on on human health effects associated with wastewater treatment and disposal was presented in Kowal and Pahren (1980). The status of knowledge on the individual organisms likely to be of concern in wetland environments is described in the following sections.

3.4.1.1. Parasites

. Craun (1979a, 1979b _in_ Kowal and Pahren 1980) concluded that the use of disinfection alone for the treatment of surface water was ineffective for the removal of cysts of _Giardia lamblia_ (a parasite that affects various species of mammals, including man). Fox and Fitzgerald (1979 _in_ Kowal and Pahren 1980) determined that only a few cysts were necessary to cause an infection in susceptible hosts. No information is available concerning the survival rates of parasites in wetland environments.

3.4.1.2. Viruses

Preliminary conclusions are that virus survival is limited under natural conditions in wetland ecosystems. The lack of reliable, standardized, and economical means to detect and quantify enteric viruses in water has hampered efforts to determine the public health significance of viruses in wetland treatment systems. Treatment of wastewater will reduce, but not eliminate, viruses from effluents (Berg et al. 1976; Grimes 1982). Adenoviruses and enteroviruses can remain viable in water for long periods of time, but are susceptible to chlorination. Gastroenteritis of suspected viral etiology is the major waterborne illness in the United States (Haley et al. 1980 _in_ Shiaris 1983). Rotavirus, and particularly parvovirus, were mentioned by a number of researchers as important causes of gastroenteritis. AING (Acute Infectious Nonbacterial Gasteroenteritis) and types A and B hepatitis viruses are the major diseases of concern (Fox 1974; Shiaris 1983), but no studies of these organisms are known to have been performed at wetland treatment sites.

It is known that viral resistance to chlorination varies between genetic strains of the same virus as well as between different toxonomic groups (Kelley and Sanderson 1958, Liu et al. 1971). Viruses also generally are present in secondarily treated wastewater even after chlorination (Shuval 1976; Sproul 1976). Furthermore, it has been assumed in the past that viruses cannot survive drinking water treatment and that viruses cannot survive in the presence of free chlorine residuals. However, in several cases viruses have been isolated from drinking water (Hoehn et al. 1976; McDermott 1974).

The technical difficulties associated with the measurement of virus concentrations in wetlands were reviewed by Wellings (1979). One example is that many viruses readily adsorb to natural occurring silts and clays (Goyal and Gerba 1979 _in_ Shiaris 1983). Goyal and Gerba (1979, _in_ Kowal and Pahren 1980) concluded that no single enterovirus or coliphage could serve as the model for the manner in which a virus is adsorbed on soil, and similarly, that no single soil could serve as the model from which the adsorptive capacity of other soils could be measured. Polio virus, which has been used as an indicator in most adsorption studies, was described as an unsuitable indicator by Katzenelson and Kedmi (1979 _in_ Kowal and Pahren 1980). It is apparent that no single virus can currently serve as an adequate indicator of viral pollution (Grabow 1968 _in_ Shiaris 1983).

Wellings (1975, 1979) determined that the only detectable virus concentrations measured during several years of extensive testing at several wetland treatment sites in Florida cypress domes occurred in association with the disturbance of the upper layers of soil. Studies to determine the effects of higher concentrations of virus by the application of unchlorinated wastewater were not possible at these sites because State of Florida regulations require chlorination of effluents (Fritz and Helle 1978). Bitton et al. (1975), indicated that 99% of the polio virus added to the cypress dome was adsorbed onto the sandy clay loam underlying the dome and could not be eluted by the addition of rain water.

Kadlec (1979) obtained very different results for the Houghton Lake peatland. Reovirus and polio virus were detected in all samples collected from the wetland and the treatment facility. Based on the sampling results, it was determined that the surface water of the wetland was a hostile environment for polio virus but not for reovirus.

Wastewater in stabilization ponds and effluent sprayed from sprinkler guns onto a forested area in Pennsylvania were examined weekly for viruses, _Shigella_, and _Salmonella_ (Reynolds 1974). Streams and wells on the site also were monitored. No viruses or pathogenic organisms were detected.

More practical and efficient detection methods are required to assess the health significance of pathogenic viruses. Common techniques currently in practice may detect 1/10 to 1/100 of the viruses present in water (Shiaris 1983). Once detected, removal of viruses by current treatment techniques vary and may be dependent upon the properties of the individual viruses (Christie 1967; Shuval 1970; Sheladia et al., 1982, *in* Shiaris 1983).

3.4.1.3. Bacteria

Shiaris (1983) reported that bacterial pathogens, compared to all other pathogens, are the most susceptible to wastewater treatment. The most numerous pathogen in municipal wastewater, and consequently of most public concern, is *Salmonella* spp. *Salmonella* may survive long periods in water, yet high doses are required for infection (Yoshpe-Purer and Shuval 1972 *in* Shiaris 1983). Shiaris (1983) reviewed several pathogenic bacterial species of major concern including *Campylobacter fetus*, subspecies *jejuni*; *Shigella* spp.; and *Leptospira*. The occurrence of pathogens in water does not always reflect the incidence of disease, or the amount of fecal pollution to which the water has been subjected. Pathogens of minor importance included the following: *Brucella* spp.; *Citrobacter* spp.; *Clostridium* spp.; *Coxiella burnetii*; *Enterobacter* spp.; *Erysipelothrix rhusopathiae*; *Francisella tularensis*; *Klebsiella* spp.; *Legionella pneumophila*; *Listeria monocytogenes*; *Mycobacterium tuberculosis*; *Proteus* spp.; *Pseudomonas aeruginosa*; *Serratia* spp.; *Staphylococcus aureus*; and *Streptococcus* spp. (Shiaris 1983). No studies of these pathogens have been performed to date at wetland treatment sites.

Kadlec and Tilton (1979) reviewed data on concentrations of fecal coliform bacteria at wetland treatment sites and concluded that their removal is dependent upon the residence time of the wastewater in the wetland, its contact with the soil, and the flow rate. Less removal was reported for deepwater situations. Background levels of coliform bacteria were determined to be high, but variable, in freshwater wetlands. Because of this natural variability, they recommended the use of another enteric bacterium for the determination of removal rates and effectiveness in wetlands.

Standridge et al. (1979 in Geldreich 1980) reported that high fecal coliform concentrations at a public swimming beach in Wisconsin were due to a combination of wastes from mallard ducks and meteorological events. However, Brierly et al. (1975) reported opposite results in a study of enterococcus and coliform bacterial populations at a waterfowl refuge in the Southwest. Hussong et al. (1979 in Geldreich 1980) determined that the bacterial flora of wild Canada geese and whistling swans contained significantly more fecal coliforms than fecal streptococci. Thus the effects of temporary concentrations of waterfowl during migration periods must be taken into consideration during the measurement of bacterial concentrations at wetland treatment sites if fecal coliform organisms are used as indicators of water quality.

3.4.1.4. Toxic Organic Compounds

Few data are available concerning toxic organic compounds found in sewage (Pahren et al. 1979 in Shiaris 1983). In addition to toxic organics originally present in sewage, microbial populations may themselves produce toxic materials metabolically. Municipal wastewater contains numerous compounds that may supply substrates for microbial growth. These microbes are capable of transforming pollutants to nontoxic forms or activating pollutants to more toxic compounds (Shiaris 1983).

Cell tissue culture assays (Cody et al. 1979 in Kowal and Pahren 1980) and human blood cells (Solomons 1979) can be used to detect toxic organic compounds. Mutagenic effects of organic compounds were noted in samples from advanced wastewater treatment (AWT) plants that treated domestic and industrial wastewater. Little or no effects were measured in samples from plants that treated only domestic wastes (Rapaport et al. 1979 in Kowal and Pahren 1980). Pahren and Ulmer (1979 in Kowal and Pahren 1980) measured the concentrations of 70 trace elements in effluents from four Advanced Wastewater Treatment (AWT) plants. They reported that elements which were not routinely monitored in water quality investigations were not present at detectable levels or at levels hazardous to human health.

The potential for transmission of high concentrations of toxic organic substances to humans through wetland food chains has not been estimated. This potential would vary among different types of wetlands and different types of soil, vegetation, and wildlife. Most trace metals, however, appear to accumulate in sediments rather than in plants (Giblin 1983). However, over long periods of time these substances may begin to accumulate in the consumer levels of wetland food chains (Tilton and Kadlec 1979). Metabolic wastes such as nitrite may accumulate in the environment, or the microbes may act as a source for the bioaccumulation of toxic organic compounds in the wetlands food chain (Shiaris 1983).

3.4.2 Effects on Plant Health

Plant health is of concern because of the potential for: (1) transmission of disease to agricultural crops; (2) loss of food and habitat for wildlife; and (3) reductions or changes in the macroinvertebrate communities that form the basis of the wetland food chains.

Epstein and Safir (1981) studied wastewater irrigation and plant disease in an old field in Michigan, reviewed the literature regarding disease related damage to vegetation from the application of wastewater, and conducted laboratory experiments to compare the survival of several species of fungi in wastewater and in tap water. They determined that any phytopathogenic fungi present in the wastewater probably are of little consequence because: (1) in order for a plant infection to occur, the fungus must contact a wounded cell; (2) most plant fungi are transmitted by a specific vector; (3) chlorination of wastewater may kill phytopathogenic fungi; and (4) there did not appear to be differences between wastewater and tap water constituents that would be significant for plant pathology.

Several other investigators (Zeiders 1975 and Zeiders and Sherwood 1977) have reported more tawny blotch on irrigated reed canary grass plants than on nonirrigated plants. In these studies, the incidence of disease was reduced by a three-cutting harvest system. Some clones of this species were determined to be resistant to the disease.

Excessive accumulation of trace metals could adversely affect plants directly or by producing imbalances in nutrient concentrations. However, no such problems have been noted to date by researchers at land application sites (Chang and Page 1978, Hinesly et al. 1978).

3.4.3 Effects on Wildlife Health

The majority of the organisms that cause disease in wildlife already are present in wetland environments. The issue of concern with respect to wastewater addition is the creation of a set of conditions that would increase the populations of disease organisms dramatically. This could in turn increase the susceptibility of wildlife to these pathogens and reduce wildlife viability.

Bellrose and Low (1978) noted that the study of disease in populations of waterfowl presently is at an early stage of development. Sanderson et al. (1980) indicated that the greatest interest in diseases and parasites of wildlife is the potential for their transmission to man and other animals. The potential for transmission of disease organisms to wildlife and humans through wastewater is a serious concern to federal and state wildlife biologists and regulatory personnel.

The major potential disease/health related impacts that could be associated with wetlands receiving wastewater include:

- The production of toxin by Clostridium botulinum, a bacterium that requires anaerobic conditions;
- The introduction of pathogenic organisms in wastewater from dairies, livestock or poultry farms or processing facilities, egg-washing plants, or other facilities where such organisms may exist;
- The introduction of human parasites and pathogens in wastewater that could also affect wildlife;

The relationships between toxicity and disease in wildlife and the potential for wildlife acting as vectors for human and domestic animal disease are summarized in Figure 3.4-1. Figure 3.4-1 also outlines methodologies for assessing disease impacts on wildlife populations (specific methodologies are also given in Appendix A).

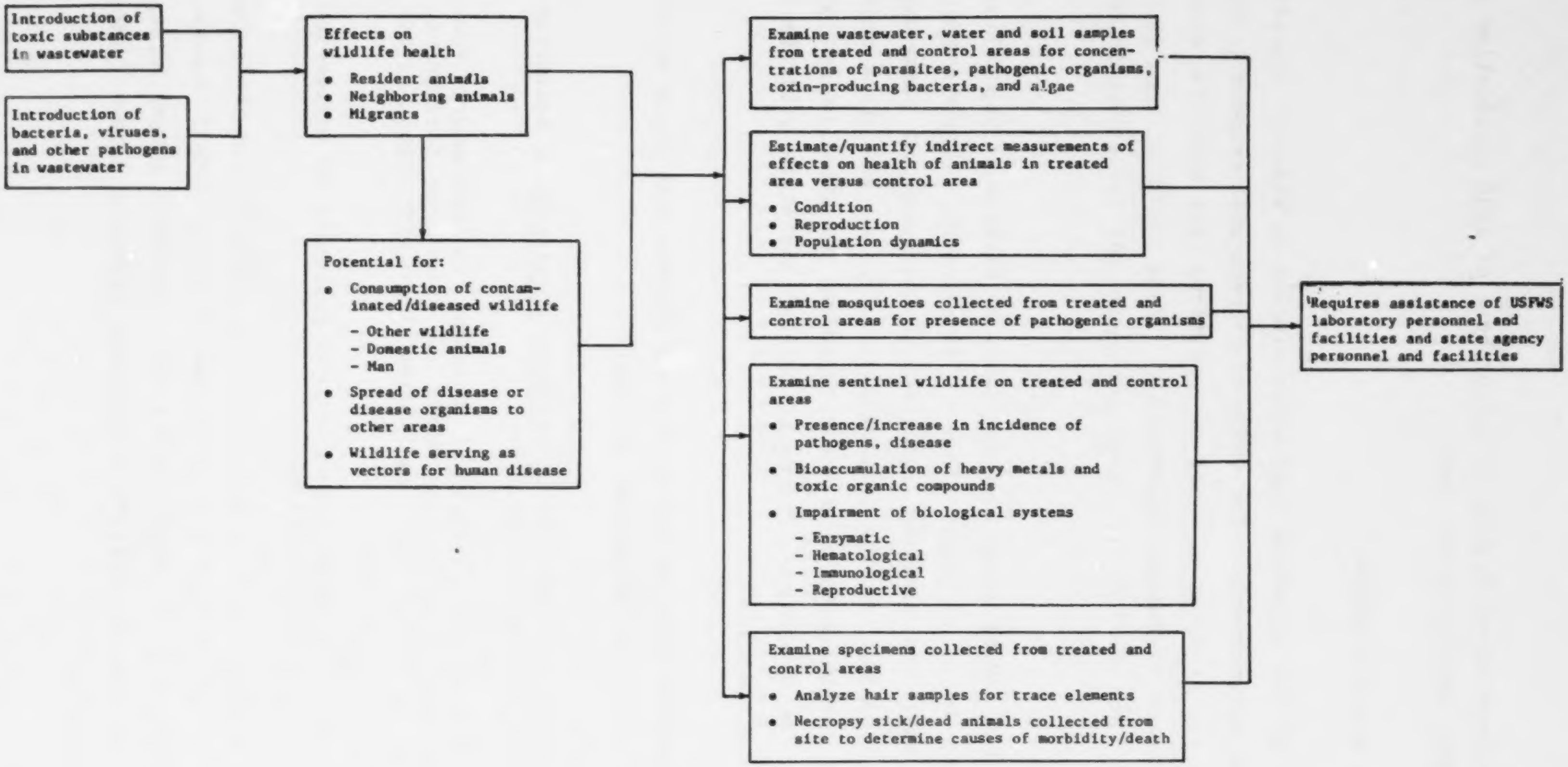

Introduction of toxic substances in wastewater
Introduction of bacteria, viruses, and other pathogens in wastewater
Effects on wildlife health
• Resident animals
• Neighboring animals
• Migrants
Potential for:
• Consumption of contaminated/diseased wildlife
- Other wildlife
- Domestic animals
- Man
• Spread of disease or disease organisms to other areas
• Wildlife serving as vectors for human disease
Examine wastewater, water and soil samples from treated and control areas for concentrations of parasites, pathogenic organisms, toxin-producing bacteria, and algae
Estimate/quantify indirect measurements of effects on health of animals in treated area versus control area
• Condition
• Reproduction
• Population dynamics
Examine mosquitoes collected from treated and control areas for presence of pathogenic organisms
Examine sentinel wildlife on treated and control areas
• Presence/increase in incidence of pathogens, disease
• Bioaccumulation of heavy metals and toxic organic compounds
• Impairment of biological systems
- Enzymatic
- Hematological
- Immunological
- Reproductive
Examine specimens collected from treated and control areas
• Analyze hair samples for trace elements
• Necropsy sick/dead animals collected from site to determine causes of morbidity/death
Requires assistance of USFWS laboratory personnel and facilities and state agency personnel and facilities

Figure 3.4-1. Wildlife toxicity/disease considerations (figure created by K. Brennan, WAPORA Inc.,1983).

The USFWS Wildlife Health Laboratory in Madison, Wisconsin, has identified the following wildlife diseases as potentially associated with wetland fauna:

- Avian cholera;
- Avian botulism;
- Lead poisoning;
- Salmonellosis;
- *Giardia* infestation;
- Leptospirosis;
- Listeriosis;
- Avian tuberculosis; and
- Mycotic (fungal) diseases.

The diseases listed above occur in natural wetlands. Both resident and transient wildlife could introduce or become infected by these diseases at a wetland treatment site. Friend (1983) reported that waterfowl and shorebirds are the groups at greatest risk from sewage effluent discharges to wetlands. Wetlands support these gregarious species and they are attracted to sites of sewage discharge. This situation is compounded by the fact that available wetland acreage is decreasing at a rate of 300,000 acres per year (Ladd 1978 *in* Friend 1983). Management efforts to maintain current waterfowl populations result in greater use of available habitat, thus habitat quality is directly related to disease problems (Friend 1983). Because of this potential for health problems, sewage disposal in wetland environments has serious wildlife health implications (Friend 1983).

No literature reviews on the effects of wastewater treatment facility operation or wetland treatment systems on wildlife health are known to exist. Information on the major diseases of wildlife, with particular emphasis on those diseases that are transmissible to domestic animals and man, is contained in the draft US Fish and Wildlife Service refuge manual (USFWS 1980). The manual also includes guidelines for preventive management and for collection, preservation, and shipment of specimens. Herman (1969), as well as Friend (1982) provided a general discussion of the impacts of disease on wildlife populations, and Bellrose (1976) discussed the types of diseases that specifically affect waterfowl.

3.4.3.1. Viruses

Kalter and Millstein (1974) reviewed animal-associated viruses in water and reported that relatively little research has been done in relation to the contamination of water by animal-associated viruses, or the effects on such contamination from flooding, draining, damming, or irrigation. This lack of information prevents estimation of the potential impacts of viruses on animal and human health.

In one of the few studies conducted to date, Berner and Dame (1976) reported that populations of several species of nuisance mosquitoes were reduced in the domes by maintaining a constant water level through the introduction of treated wastewater. As part of this study, blood of sentinel animals (chickens) placed in the treated domes, in control domes, and in various locations within the nearby city of Gainesville was tested once every three weeks. Serum extracted from the blood samples was used in hemaglutin inhibition tests to determine the presence of antibodies formed against eastern equine encephalitis, western equine encephalitis, or St. Louis encephalitis. Eastern and western equine encephalitis were reported to be present in both the treated and the control domes. The researchers noted that the songbirds that may spread eastern equine encephalitis to other areas during migration periods were not present at the time when the mosquito populations were highest.

Wetlands located near agricultural areas, especially where domestic fowl are raised, are sites where viral disease organisms might be present. Many viral diseases are transmitted to wildlife from domesticated animals, and wetland discharges containing agricultural wastes from poultry processing plants, feedlots, and other animal industries are more likely to contain viral pathogens transmissible to wildlife than those containing domestic animal wastes (Friend 1983). The USFWS acknowledges that turtles and waterfowl can contract tuberculosis. Live polio and tuberculoses viruses, used to vaccinate poultry may persist through the sewage treatment process and enter a wetland ecosystem. This is especially likely if sludge is used as fertilizer on adjacent agricultural lands and the runoff from these lands enters the wetland.

3.4.3.2 Bacteria

Bacteria are normally present in wetland fauna. Two animal pathogens associated with wetlands receiving wastewater are *Aeromonas*, a disease producer in birds, fish, and reptiles, and *Salmonella*, which affects turtles. Hemorrhagic disease of muskrats, a bacterial disease, could be of concern if muskrat overpopulate treatment sites.

A potential exists for botulism to occur at wetland wastewater treatment sites. Botulism in vertebrates results from toxin production by *Clostridium botulinum*, an anaerobic bacterium naturally present in sediments and soils and capable of rapid reproduction under suitable conditions. Six forms of the bacterium exist (Duffus 1980). Type C and type E occur in wildlife, and type C causes illness in waterfowl and small animals. There are two strains of type C: one strain occurs in fly larvae and rotting vegetation in alkaline ponds, and the other is present in forage, carrion, and pork liver.

The route of transmission to waterfowl is through ingestion of contaminated invertebrates, particularly fly larvae that develop in dead invertebrates and waterfowl carcasses. Hunter et al. (1970) studied botulism extensively in California, and developed mitigation techniques to reduce the severity of such outbreaks. They recommended improved design of impoundments or ponds, maintenance of adequate water levels during summer and autumn, and proper sanitation.

The first outbreaks of avian botulism associated with a sewage treatment facilities were reported between 1950 and 1970 (Dr. Milton Friend, personal communication). Friend (1983) reported that outbreaks of *Clostridium botulinum* type C frequently occur in sewage ponds in California and occasionally elsewhere in the United States. Moulton (1976) tried unsuccessfully to induce botulism in sentinel mallards and American coots on treatment ponds by deliberate inoculation with *C. botulinum* and by killing invertebrates with rotenone. He postulated that activity of other microorganisms in the aquatic environment inhibited the growth of bacterial cells or destroyed the toxin. Duffus (1980) noted that salt can inhibit the growth of *C. botulinum* and that several species of microorganisms can interfere with the production of toxin by this bacterium.

Friend (1983) reviewed the persistence of pathogenic agents outside of host organisms and the chemical and physical factors that affect their survival. The probability that disease will develop is increased if environmental conditions favor the persistence of these pathogenic agents.

3.4.3.3 Toxic Organic Compounds and Trace Metals

There are a number of factors which make it difficult to test wildlife populations for effects of toxic organic compounds and trace metals. These include the following (Duffus 1980):

- Wildlife populations are genetically heterogeneous, which implies that some individuals may be susceptible to a toxic substance and others may be resistant;
- Wildlife are subject to the effects of pathogens and other factors that may increase or decrease their susceptibility to toxic substances;
- Aquatic organisms on which vertebrates feed may be able to concentrate a toxic substance in their bodies without harm or may metabolize the substance to a greater or lesser level of toxicity. This is particularly true for relatively stable toxicants such as chlorinated hydrocarbons and methyl mercury;
- Toxic substances may be transformed into more toxic or less toxic forms by the action of anaerobic microorganisms, or under certain physical conditions; and
- Many algae and other plants can absorb and concentrate toxic substances.

For vertebrates, which are mobile and feed selectively on a variety of organisms, it is possible to measure the amount of toxic substances ingested only under controlled conditions. Susceptibility also varies with the developmental stage of an individual organism, being greatest in the embryonic and larval stages and in senescence (Duffus 1980).

Duffus (1980) reviewed transformations of major trace metals and effects of metals on vertebrates. Trace metal contamination may reduce reproduction and survival of waterfowl. Heinz (1979) and Finley and Stendell (1978) reported such reductions for mallard and black ducks, respectively, that were fed low doses of methyl mercury. White and Finley (1978) and White et al. (1978) noted similar adverse effects from ingestion of cadmium by mallards. Toxic effects due to ingestion of trace metals at wetland treatment sites, in combination with lead poisoning because of ingestion of lead shot, could cause decreases and reproductive losses in waterfowl.

The levels of trace metals in wastewater from industrial sources are usually low, and may be further diluted during passage through the wetland. The direct effects of trace metals on vertebrates that drink the water are therefore likely to be chronic rather than acute. Biomagnification of metals by food organisms would increase the likelihood of chronic toxic effects. Also, under certain circumstances, toxic substances accumulated in an individual could kill the organism if it experiences sudden or severe stress.

3.5 Issue Category V: Overloading and Stress Conditions

Addition of wastewater to a wetland may overload the system, producing stress, and is an issue of concern. Stress on a wetland receiving wastewater may lessen the system's productivity by shunting energy into different metabolic pathways (i.e., respiration increases, rates of photosynthesis decrease), interfering with the normal energy flow patterns. This may produce a variety of little known but potentially significant ecological effects.

Stress ecology is a rapidly developing area of basic research. Barrett et al. (1976 in Knox 1980) defined a stress as a system's response to a perturbation (stressor) that may be either foreign or natural to the system but applied at an excessive level. The following guidelines for testing responses to various perturbations and for evaluating the responses of ecosystems to stressors were developed by the above authors, and could be used in designing the Phase II portion of the present study:

- If possible, both structural and functional ecosystem parameters should be employed in stress effect studies. The use of a "state variable" approach facilitates balancing and integrating structural and functional aspects, and is recommended;
- Studies involving stress-effect evaluations should include ecosystems of three levels of magnitude: microcosm, semi-natural, and natural;

- A concerted effort should be made to establish standardized, ecosystem-level environmental indexes, both structural and functional, for future stress investigations;
- Perturbation application and stress-response analyses should be designed to provide for an integrative, predictive model as the end result;
- Responses to pertubations should be tested and evaluated by means of an interdisciplinary, problem-solving approach;
- Stress studies should be designed to provide knowledge useful for interface management between man-made and natural ecosystems; and
- Future ecosystem pertubation studies should attempt to include contributions from personnel in the biological, physical, and social sciences.

The major focus in stress ecology has been the measurement, evaluation, and prediction of the effects of natural and man-induced stressors on the structure and function of ecosystems, particularly the effects on community stability and species diversity. Because the term "stability" has been used in many ways, researchers in recent years have proposed that the terms persistence, resistance, and resilience be used instead (Knox 1980). Definitions proposed for these terms are as follows:

- Persistence - constancy in a community over time, irrespective of the perturbation;
- Resistance - the ability of a community to remain unaffected by perturbations;
- Resilience - the ability of a community to recover to some persistent state; and
- Elasticity - the ability to absorb perturbation without drastic changes in a community.

Two additional concepts, "assimilation" and "significance,"also need clarification. Assimilation is the response at the community level to "insult" (Buffington et al. 1980). Assimilation is a function of the relative inertia, resiliency, and elasticity of the community. In simpler terms, assimilative capacity is the ability of an ecosystem to receive a waste discharge without significant alteration of the structure of the indigenous community (Cairns 1976). The definition of significance proposed for use here is that synthesized by Buffington (1976):

> "An impact is significant if it results in a change that is measurable in a statistically sound sampling program and if it persists, or is expected to persist, more than several years at the population, community, or ecosystem level."

These authors recently proposed that some aspects of irreversibility be present for an impact to be considered significant (Buffington et al. 1980). They noted that insults to the functional integrity of communities are likely to result in changes that cannot be accommodated by natural processes.

3.6 Issue Category VI: Design, Operation, and Monitoring Considerations

The state of the art in wetland treatment systems design has been described by Hammer and Kadlec (1982), Kadlec (1982), WEPA (1981), Bastian and Reed (1979), Reed and Bastian (1980), Stowell et al. (1980), Sutherland (1977), Fritz and Helle (1977) and Tchobanoglous et al. (1980). Bastian and Reed (1979) included overviews of research conducted at major long-term treatment sites in California, Florida, Massachusetts, Michigan, and Wisconsin. Examples of site suitability studies are those of Yonika and Lowry (1979) in Massachusetts, and Sutherland (1977) in Michigan. Sutherland (1982) assessed the economics of wastewater application in Michigan wetlands. A comprehensive overview of the features that make a wetland effective in renovating wastewater, and the effects of wastewater to wetland ecosystems was prepared by Kadlec and Tilton (1979) and Hammer and Kadlec (1982).

Other documents on the status, feasibility, and use of this technology are in preparation. Based on information from researchers and agency personnel working in this area, it appears that several design manuals or literature reviews will be available in the near future. The environmental requirements of various groups of wetland organisms that may be used to treat wastewater, and an assessment of the potential of these species for such use, were given in Colt et al. (1979, 1980a, 1980b) and Stephenson et al. (1980).

3.6.1 Design

Apart from the case histories and studies described above, little information exists on the design of wetland wastewater treatment facilities. Nor have key questions regarding construction have not been completely addressed in the literature. Design criteria are not currently available to predict the waste assimilation performance of natural wetlands. State-of-the-art reports include those by Culp and Tchobanoglous (1980), Hammer and Kadlec (1982) Sutherland (1977) and Fritz and Helle (1977).

A consideration that warrants attention in the earliest design stages is mitigation of the adverse impacts of construction activities. Construction impacts are site-specific, and will vary with locality, topography, season of the year, engineering technology, and other factors. Diking, ditching, and grading can permanently affect or destroy the entire character of a wetland. Darnell (1976) reviewed effects of construction activities on wetlands, and described three general impact categories: (1) immediate impacts taking place during construction; (2) effects that occur during the stabilization period after construction; and (3) permanent alterations from construction or subsequent management. Most of the adverse effects of construction are related to direct elimination of habitat, changes in hydrology, or effects of erosion.

A variety of construction methods have been used at existing wetland treatment systems. At Drummond, Wisconsin, a surface walkway system was laid directly on the peatland to permit the laying of pipe and the movement of people. At Houghton Lake, Michigan, a similar walkway was constructed slightly above the surface of the peatland. At Bellaire, Michigan, a gravel berm and pathway were extended into the forested wetland. At Kincheloe, Michigan, a point-edge discharge ditch was used.

Hammer and Kadlec (1982) summarized information concerning the treatment of wastewater by wetland irrigation, and identified several major principles that are important in designing such systems. Table 3.6-1 summarizes major factors identified by Hammer and Kadlec (1982) which affect performance of wetland treatment systems. Treatment performance by wetlands was found to be "roughly correlated with overall system features" (see Section 3.1.2.2), but treatment effectiveness was determined not to be fully predictable at this time. Additional information is still required to effectively model and predict treatment effectiveness. The study presented a simplified model of wetland treatment, which is the initial step in developing predictive capa-

Table 3.6-1. Potential factors affecting the performance of wetland treatment systems (from Hammer and Kadlec 1982).

Factor	Probable Effects	Problems in Data Interpretation
Water depth	Affects residence time and flow characteristics. Encourages some species/processes while hampering others.	Controlled experiments have not been completed. Insufficient data, in operation reports.
Residence time	Long residence times should improve wastewater treatment, but may not, if due to increased depths.	Difficult to determine accuurately due to channelization. Few data available. Controlled experiments have not been completed.
Nutrient Concentrations & Loading Rates	While removal rates should increase with concentration, each system will likely exhibit rate limits.	Data are influenced by other factors whch have not been accounted for.
Cover Type & Climatic Conditions	Largely unknown, but high productivity should enhance nutrient removal.	Insufficient data.
Type of Substrate/ Soil	Largely unknown.	Insufficient data.
Discharge Schedule	Unknown.	Insufficient data.
System Age	Nutrient retention rates may change with time due to saturation phenomena and to changes in the ecosystem.	Data are influenced by other factors which have not been accounted for. Site histories for older systems are often quite sketchy.

bilities. The fate of nutrients and pollutants in wetlands is determined primarily by sedimentation, plant uptake, and soil and microbial processes. The area of wetland affected is related to the quality of the effluent, age and type of wetland, and the hydraulic regime present. Hammer and Kadlec (1982) concluded that the quality of water passing through a wetland is controlled by water movement, mass transport to wetland ecosystem compartments, and nutrient retention within each compartment (as described by mathematical kinetics). Wetland hydrology must therefore be fully understood to enable proper design of waste treatment systems.

Hammer and Kadlec (1982) presented a simplified two-part model that included a mass transport model for the "zone of rapid removal" and a "saturation" model for a changing zone of stabilized activity near the discharge (Figure 3.6-1). Long-term performance was related to overall material balances (of nutrients and pollutants) in a given wetland system. Figure 3.6-2 summarizes the various ecosystem compartments used by Hammer and Kadlec (1982) in their model. Movement of nitrogen was shown to be a predictable function of the distance from the discharge when the model was applied to the Houghton Lake peatland system (Figure 3.6-3).

Analyses of the economic aspects of designing wetland wastewater treatment facilities have been conducted by Hammer and Kadlec (1982), Sutherland (1978, 1983), and Fritz and Helle (1970). Sutherland (1983) determined that capital costs were related primarily to the distance from the stabilizing ponds to the wetland according to the relationship $C = 129\ D + 288$, where C = cost (in thousands of dollars) and D = distance in miles (Figure 3.6-4). This relationship was for applications of less than 1 inch/week. Sutherland (1982) also provided information on costs for the Vermontville and Houghton Lake, Michigan, wetland treatment sites (Hammer and Kadlec 1982 also presented detailed economic information on Houghton Lake.) Based on a review of data given in Sutherland (1975) and Fritz and Helle (1970), Hammer and Kadlec (1982) concluded that where suitable sized wetlands were available in close enough proximity, the wetland treatment alternative is cost-effective for small rural communities.

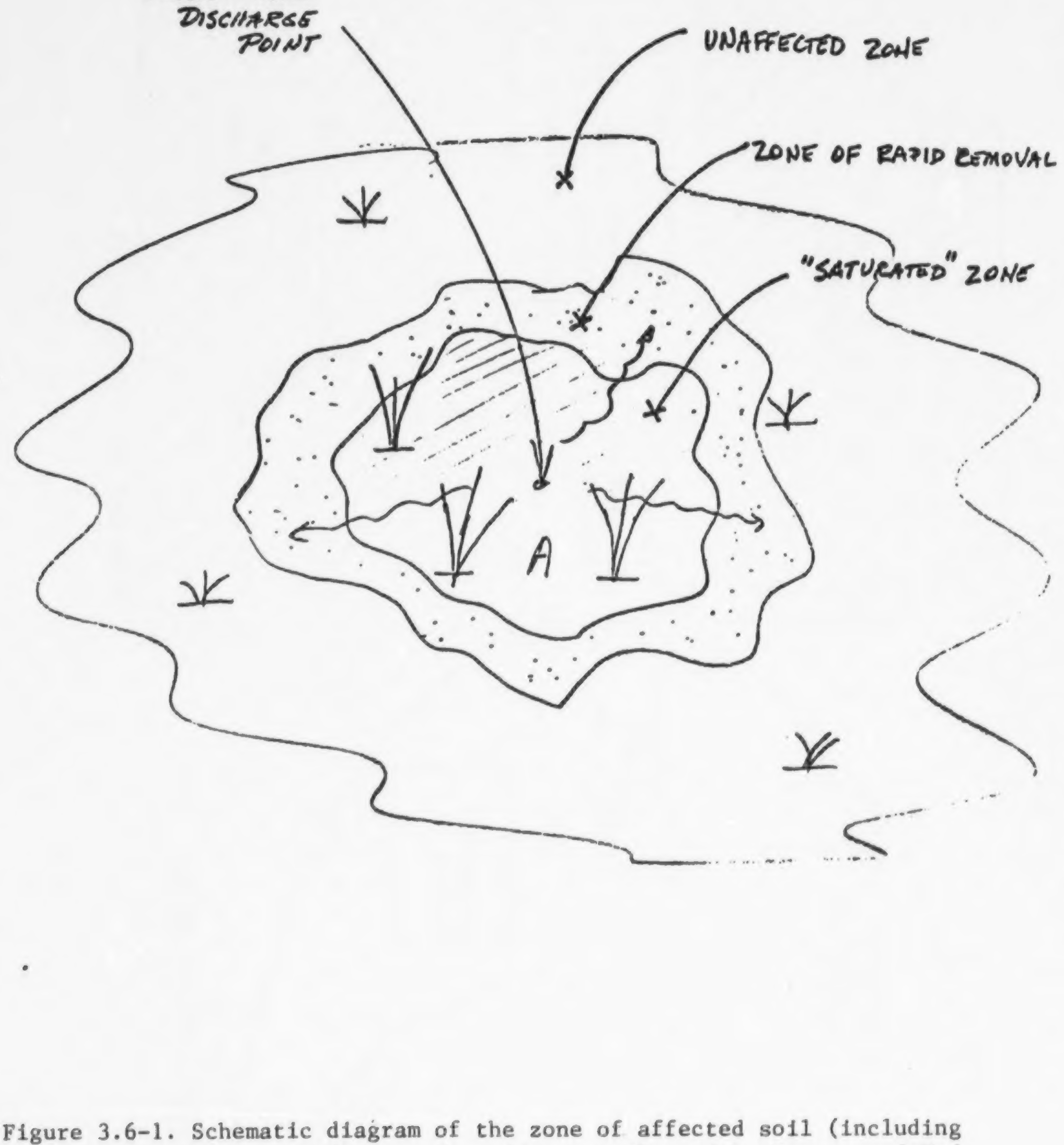

WASTEWATER DISCHARGE POINT
UNAFFECTED ZONE
ZONE OF RAPID REMOVAL
"SATURATED" ZONE
A

Figure 3.6-1. Schematic diagram of the zone of affected soil (including the saturated zone and zone of rapid removal) used by Hammer and Kadlec (1982) to model wastewater discharges in wetlands.

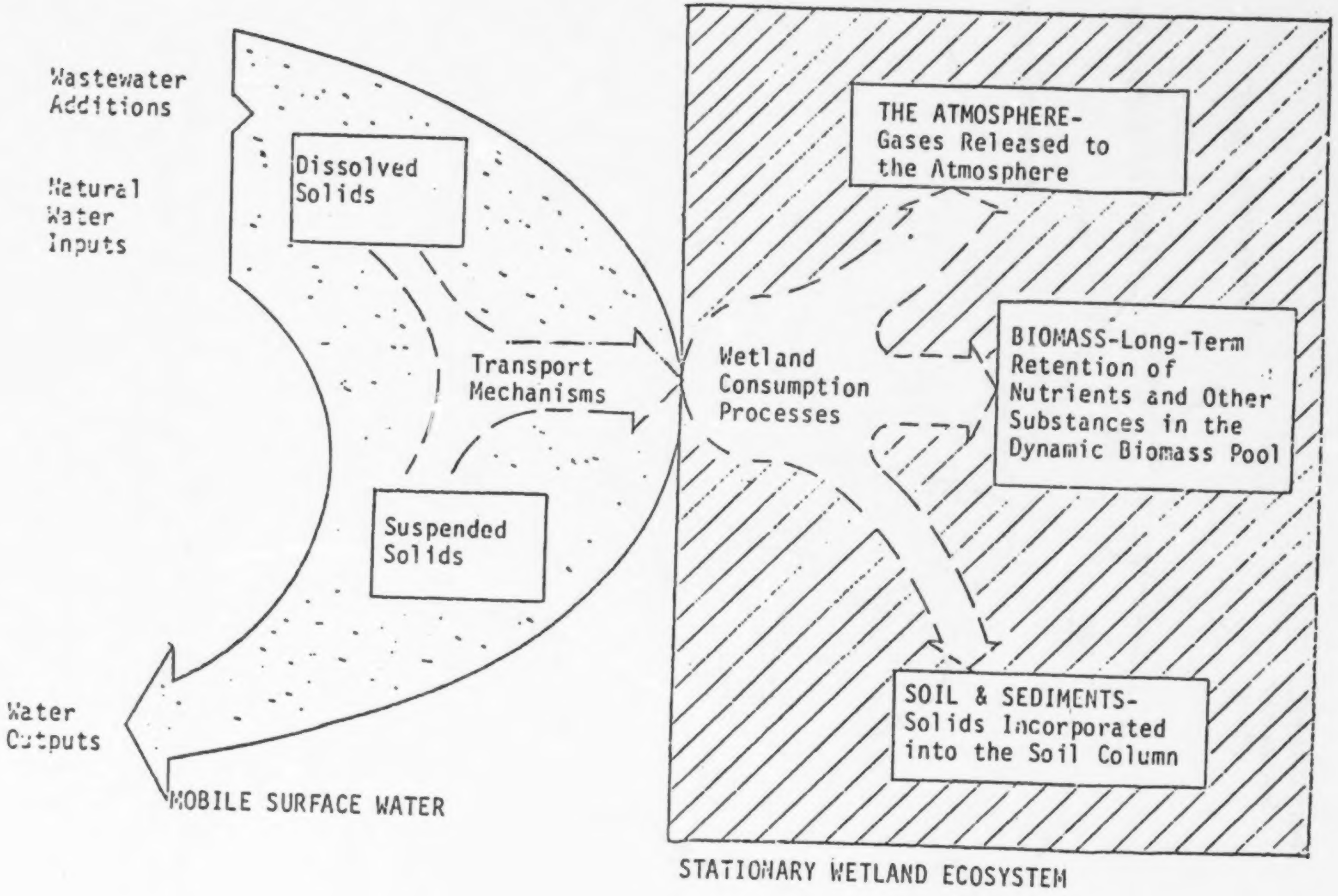

Wastewater Additions
Natural Water Inputs
Water Outputs
Dissolved Solids
Suspended Solids
Transport Mechanisms
MOBILE SURFACE WATER
Wetland Consumption Processes
THE ATMOSPHERE- Gases Released to the Atmosphere
BIOMASS-Long-Term Retention of Nutrients and Other Substances in the Dynamic Biomass Pool
SOIL & SEDIMENTS- Solids Incorporated into the Soil Column
STATIONARY WETLAND ECOSYSTEM

Figure 3.6-2. Simplified compartmental model for use in wetland treatment system design (from Hammer and Kadlec 1982).

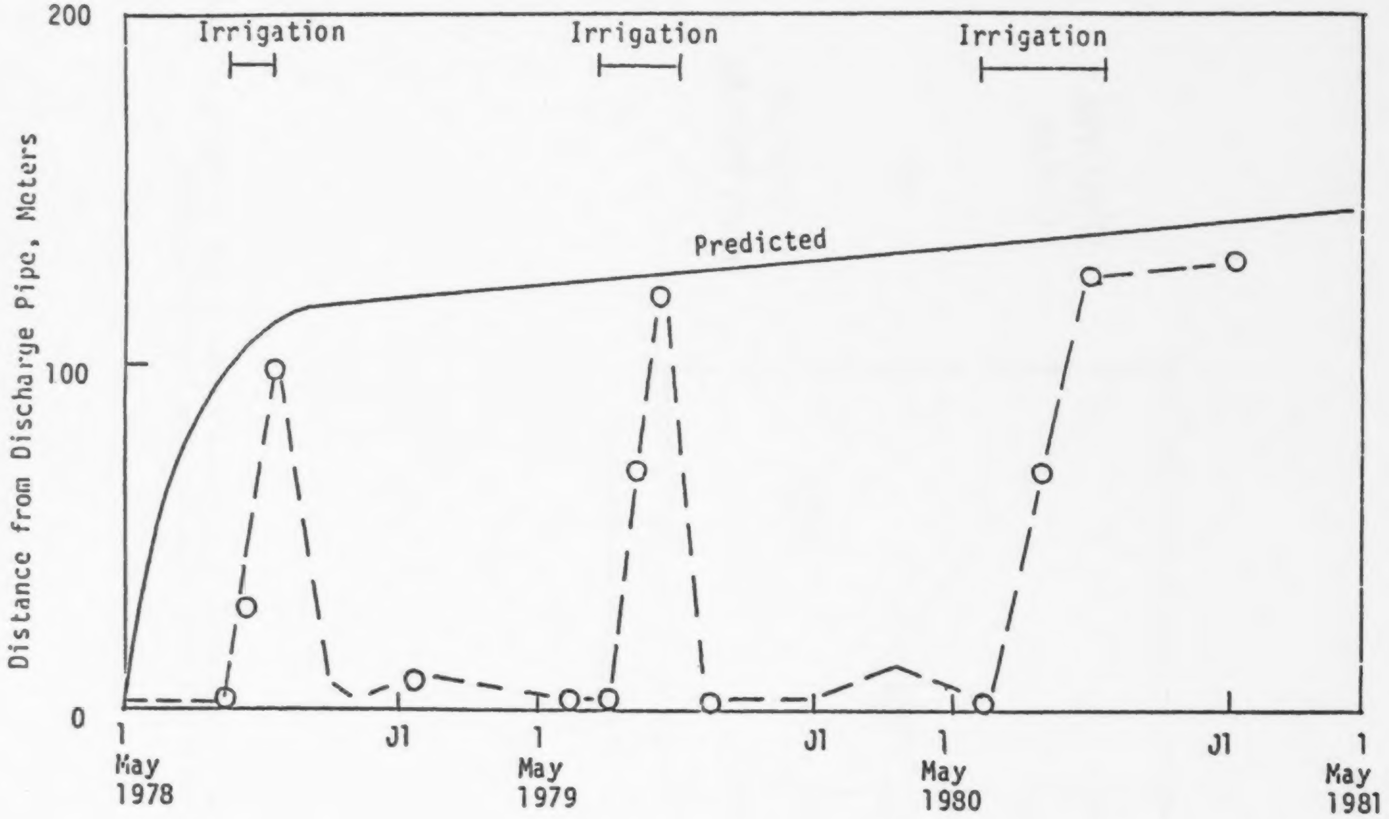
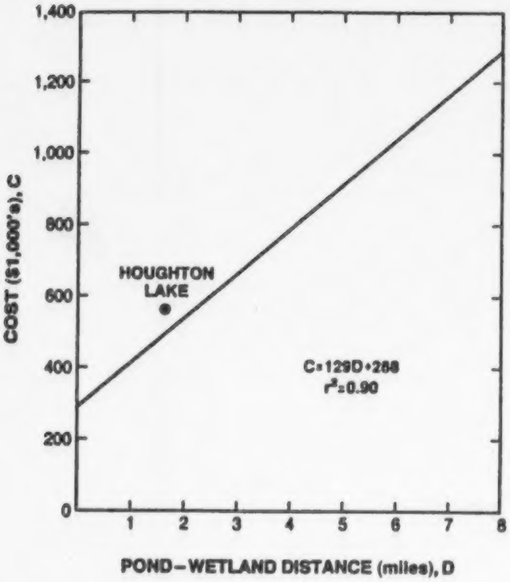


Figure 3.6-3. Movement of ammonia-nitrogen ($NH_4^+ - N$) concentration fronts in surface waters (concentraions in mg/l) at the Houghton Lake Michigan treatment site (from Hammer and Kadlaec 1982).



Wetland Costs

VS

Distance from Ponds

Figure 3.6-4. Relationship between cost and distance from stabilizing pond to wetland Michigan wetlands (from Sutherland 1983).

3.6.2 Operation and Maintenance

Hammer and Kadlec (1982) provide general guidelines for operation and maintenance of wetland treatment systems, although they state that more data are needed before fully suitable techniques can be devised. Several options are available for the introduction of wastewater to the wetland: the discharge can be continuous, seasonal, or intentionally intermittent. No data exist to determine the preferred method for a particular situation, and there is little experience with winter operation. Several year-round discharges are under study, including facilities of Kincheloe, Michigan, Listowel, Ontario, and Humboldt, Saskatchewan. A batch mode is used at Humboldt (Lakhsman 1980). Some treatment sites have spring discharges, others have spring and autumn discharges, and one site has a discharge only during the autumn. None of these modes of operation has been selected on the basis of any analysis of the performance of the wetland system.

The maintenance requirements of a wetland treatment system have received little study and are therefore poorly known. The term "maintenance" implies some corrective action would be taken at the plant site to compensate for an observed effect within the wetland. Only two policies in this regard have been followed to date: a total "hands-off" attitude, and the avoidance of deep-water situations. The latter strategy is being employed at Drummond, Wisconsin, and at Houghton Lake, Michigan. The philosophy behind this strategy is simply to avoid the drowning of vegetation and the increasing of erosion in the wetland.

3.6.3. Monitoring

No monitoring requirements have yet been developed by regulatory agencies for wetland treatment systems. There is some reluctance at both the state and national levels to set a precedent in this area. The task is difficult because a wetland ecosystem does not fit the traditional pattern of a sewage treatment plant and a receiving water body. At least two points of view have arisen. These are: (1) that the wetland is a receiving water body and that the influent should be controlled; and (2) that the wetland is a part of the treatment plant, and therefore the outfall from the wetland should be controlled. In either case, guidelines need to be established for concentrations of water quality parameters at the exit from a wetland ecosystem that is connected to a wastewater treatment plant (Reed and Kubiak 1983). Difficulties can arise from the fact that wetlands in the natural state may violate certain accepted water quality constraints, such as limitations on suspended solids.

3.7 Issue Category VII: Constructed Wetlands

Creating new wetland areas for wastewater treatment has gained considerable support as an alternative to the possible digradation of existing wetlands. Constructed systems have demonstrated the ability to treat effluent to advanced secondary and seasonally to advanced treatment standards while increasing vegetation production and wildlife habitat. Constructed wetlands can be used to treat applied wastewater without degrading existing high quality habitats.

Constructed wetlands present a treatment option both in areas where wetlands do not exist, and where natural wetlands are restricted from use. Constructing a wetland treatment system has several benefits. These wetlands can be designed for greater operational control than natural wetlands. Treatment cells can be constructed to allow for alternating application and resting phases, and flows can be controlled or adjusted for seasonal variations and needs (USEPA 1982). Underlining a system with clay or a plastic membrane prevents percolation of partially treated wastewater to the water table.

Experiments have been conducted on artificial wetlands since the 1950's (Seidel 1976). Researchers have produced a considerable range of data from bench scale demonstration projects to full-scale facilities (Waste and Water International 1982). Table 3.7-1 summarizes the removal efficiency of constructed wetland systems in various areas of North America. The types of systems examined include:

- open marsh basins operating in a mode similar to overland flow (Small 1978);
- narrow marsh trenches with coarse-textured substrates using subsurface flow and underdrains (Pope 1981);

Table 3.7-1 Percent removal efficiency of constructed wetlands.

Author	Location	Influent	Wetland Type	Wetland Area	BOD_5	SS	P	Nitrate Nitrite	Ammonia
Small (1978)	Upton, NY	Aerated Raw Sewage	Marsh/Pond	$47m^2$	89	88	71	53	58
Pope (1981)	Laguna Miguel, CA	Screened Raw Sewage	Marsh trenches	$600m^2$	84.5	90	4.3	--	--
Water and Waste Int'l (1982)	Neshamiay Falls, PA	Aerated Raw Sewage	Marsh/Pond/Meadow	0.6ha	96	94	75	--	87
Sutherland (1979)	Vermontville, MI	Secondary	Seepage Wetland	465ha	--	--	60	7.7	94.6
Wile et al (1983)	Listowel, Ont.	Aerated Raw Sewage	Marsh trenches	$1000m^2$	75-96	84-98	71-98	--	--
Gersberg (1982)	Santee, CA	Secondary	Marsh trenches	$906.5m^2$	84	87	--	73*	--

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*Total N

- intermediary marsh channels with surface overflow (Gersberg 1982).

Despite some variability in performance, these systems demonstrate strong capabilities of treating wastewater effluent.

The viability of a constructed system is primarily limited by land availability, construction cost, and conveyance costs. Land requirements run on the order of 50 acres per mgd (Wile et al. 1983). To minimize conveyance costs, sites should be located as close to wastewater generation sources as possible. Excavation costs are minimized when the terrain is level to gently rolling, with sufficient depth to bedrock to avoid the need for blasting. As this type of system is most often underlined by a plastic membrane, it is not dependent upon the transmissivity of surficial soils.

The construction requirements for this type of wetland primarily involve excavation of the required area into the chosen configuration. Survey of the area's topography is recommended to ensure the level surface required for uniformity of flow (Wile et al. 1983). Trenches approximately 3 meters wide separated by berms suitable for travel by maintenance vehicles, have been demonstrated to be effective (Pope 1981; Gersberg et al. 1982; Lakhsman 1982; Wile et al. 1983). Trenches should have side slopes of 2:1, should be underlined with an impermeable membrane, and backfilled with soil as a rooting medium. Emergent vegetation such as cattails (Typha sp.) and bulrushes (Scripus sp.) are found locally in most areas of the country, and when transplanted in one foot diameter cores demonstrate rapid and luxuriant growth (Wile et al. 1983). Application and discharge hardware should be constructed to permit uniform concentrations of effluent over the width of the field area and to control water depth, flow rate, and detention time.

Wile et al (1983) found that marsh configuration was very important to performance efficiency. Dye studies conducted indicated that internal flow patterns in an open marsh resulted in short circuting of flow. Based on the superior treatment efficiency of marsh trenches, a gometric configuration with a length to width ratio of 20:1 is recommended.

Wetland design criteria have varied according to the types of effluent applied. Table 3.7-2 shows design parameters developed by Tchobanoglous and Culp (1980) for these wetland treatment systems. Wile et al. (1983) created a system that operates on a detention time of seven days, a water depth of 10 cm in summer and 30 cm in winter, and a loading rate of $200m^3$/ha/day (Figure 3.7-1). This loading rate was derived on the basis of the influence of evapotranspiration in summer and ice cover in winter. During the summer months, evapotranspiration exceeded 60% of the loading rate, thus increasing detention time. These conditions resulted in water stagnation, anoxia, and decreased treatment efficiency. Maintaining low liquid depths was found to circumvent these problems. During winter, ice formation reduced the wetland volume, decreasing detention time. Increasing the water depth prior to the onset of winter conditions was found to remedy this problem (Wile et al. 1983).

Pretreatment methods have varied from raw screened effluent (Pope 1981), aerated primary effluent (Small 1978), lagoon effluent (Wile et al. 1983), to effluent from an activated sludge secondary treatment plant (Gersberg 1982). Pope (1981) reported that low pretreatment levels led to clogging of the treatment system, difficulty in establishing stands of planted vegetation, and poor treatment efficiency. Based on studies at Listowel, Ontario, Wile et al. (1983) recommended a falcultative aerated treatment cell with 5 to 10 day retention time and continuous alum feed. This would reduce BOD, suspended solids, and phosphorus concentrations with minimum sludge buildup. Phosphorus removal was recommended because treatment efficiency in the wetland cell is expected to decline over time.

In most instances, the primary purpose of a constructed wetland system is nutrient removal. Numerous studies have documented the physical and microbial processes by which BOD and suspended solids are treated in such an environment. The efficiency of constructed wetlands to treat nitrogen is generally good. Gersberg et al. (1982) described experiments conducted with constructed marsh beds using mulched marsh vegetation as a carbon source for denitrification. They indicated a mean removal efficiency in the mulch-amended beds of 87% (±8%) total nitrogen and 91% (±9%) of total inorganic nitrogen. A benefit may therefore be derived by harvesting the marsh plants, grinding them for mulch, and reapplying the mulch to the wetland. Black et al. (1981) presented

Table 3.7-2. Preliminary design parameters for planning artificial wetland wastewater treatment systems.[a]

Type of system	Characteristic/design parameter						
	Flow regime[b]	Detention time, d		Depth of flow, ft (m)		Loading rate g/ft^{2}od (cm/d)	
		Range	Typical	Range	Typical	Range	Typical
Trench (with reeds or rushes)	PF	6-15	10	1.0-1.5 (0.3-0.5)	1.3 (0.4)	0.8-2.0 (3.25-8.0)	1.0 (4.0)
Marsh (reeds rushes, others)	AF	8-20	10	0.5-2.0 (0.15-0.6)	0.75 0.25	0.2-2.0 (0.8-8.0)	0.6 (2.5)
Marsh-pond							
1. Marsh	AF	4-12	6	0.5-2.0 (0.15-0.6)	0.75 (0.25)	0.3-3.8 (0.8-15.5)	1.0 (4.0)
2. Pond	AF	6-12	8	1.5-3.0 (0.5-1.0)	2.0 (0.6)	0.9-2.0 (4.2-18.0)	1.8 (7.5)
Lined trench	PF	4-20 (hr.)	6 (hr.)	--	--	5-15 (20-60)	12 (50)

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[a] Based on the application of primary or secondary effluent.

[b] PF = plug flow, AF = arbitary flow.

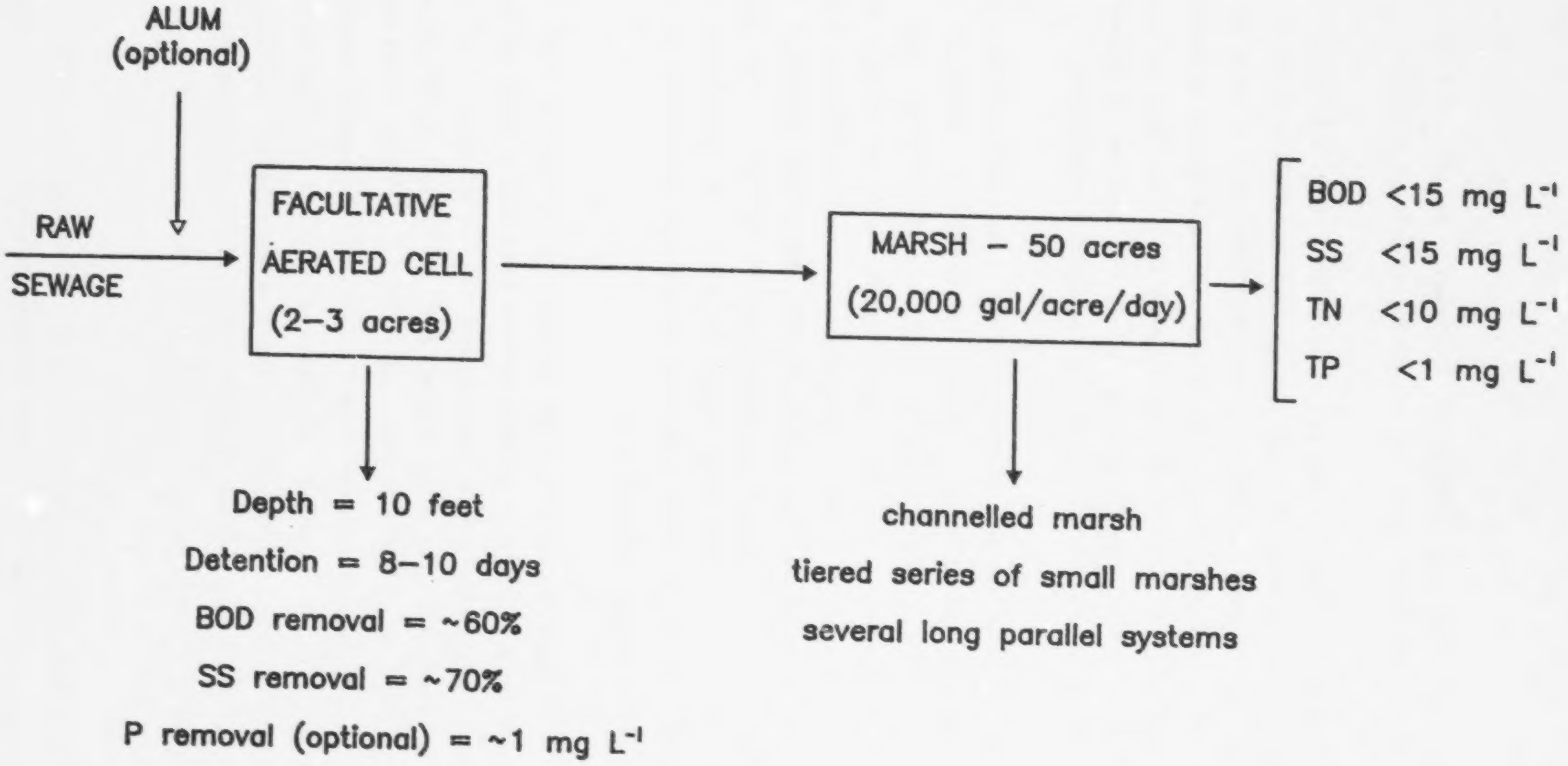

ALUM
(optional)
RAW
SEWAGE
FACULTATIVE
AERATED CELL
(2–3 acres)
Depth = 10 feet
Detention = 8–10 days
BOD removal = ~60%
SS removal = ~70%
P removal (optional) = ~1 mg L-1
MARSH – 50 acres
(20,000 gal/acre/day)
channelled marsh
tiered series of small marshes
several long parallel systems
BOD <15 mg L-1
SS <15 mg L-1
TN <10 mg L-1
TP <1 mg L-1

Figure 3.7-1 Potential design for a 1 MGD (US) marsh treatment facility (from Wile et al. 1983).

nitrogen removal data for the system at Listowel, Ontario (Table 3.7-3). These data indicate a treatment level of advanced secondary standards.

Widely varying phosphorus removal rates have been reported (Table 3.7-1). Wile et al. (1983) reported that despite substantial phosphorus removal in the Listowel facility, rates were expected to decline over time. This is due to the consumption of available adsorption sites as continuous quantities of phosphorus are applied. Nichols (1980) concluded that the only actual long-term nutrient sink in wetland treatment systems is the process of organic soil development through accumulation of partially decomposed vegetation.

The soil type placed in constructed wetland treatment systems is very important to treatment efficiency. Substrate materials employed include coarse gravel (Pope 1981, Gersberg 1982), high organic content muck (Small 1978), a mixture of subsoil, top soil, and peat (Wile et al 1983), and clay (Water and Waste International 1982). Phosphorus removal levels are dependent to a great extent upon adsorption sites in the substrate material (Kadlec 1983). There has been no comparison conducted to determine the long term adsorption capacity of these different types of soil. As previously stated, Wile et al (1983) expect phosphorus removal treatment efficiency to decline over time as sorption sites are used up.

The results of nutrient removal by vegetation harvesting have varied. Spangler (1976) reported that in a bulrush system treating primary effluent, a mid-season harvest would result in the removal of $10g/m^2$/year of phosphorus from wastewater. However, only 3 to 4 g/m^2 were estimated to be permanently removed from the system by harvesting. Wile et al. (1983) reported that, based on a single late season harvest only 8 to 10% of the annual nitrogen and phosphorus loadings would be removed. Harvesting of plant biomass is regarded as unnecessary in such systems especially since a significant portion of the plant biomass is in below ground growth. A system employing woody stem plants, which act as a relatively permanent sink may present good potential however.

Operation and maintenance requirements for constructed wetland systems include application flow control, water quality monitoring, and vegetation

Table 3.7-3. Marsh system IV effluent characteristics (monthly averages based upon weekly grab samples) (Black et al. 1981) (all values in mg/l).

Date	BOD	SS	TP	SRP	TKN	NO_2+NO_3	NH_3
August 1980	-	-	-	-	-	-	-
Sept.	2.8	5.2	0.06	0.04	1.4	0.16	0.10
Oct.	1.8	1.1	0.05	0.02	1.3	1.02	0.19
Nov.	3.2	4.4	0.11	0.03	1.5	1.46	0.07
Dec.	15	3.6	0.51	0.08	8.0	0.24	4.4
Jan. 1981	22	9	0.92	0.31	16.7	0.02	11.7
Feb.	10	7	0.67	0.34	10.4	0.01	6.2
March	18	12	0.80	0.30	9.5	0.01	5.4
April	9	8	0.45	0.13	7.3	0.10	2.3
May	14	14	0.67	0.30	7.8	0.07	1.9
June	34	34	1.81	0.65	15.0	0	7.9
July	9	9.1	0.97	0.53	11.9	0	8.8
August	9	7	0.52	0.33	7.5	0.01	5.5

control. Flow control is necessary for the maintenance of aerobic conditions within the marsh to achieve maximal treatment efficiency and to limit potential odor problems. Pope (1981) reported sludge buildup and the necessity of raking the marsh surface to maintain flow control in a system treating raw unscreened effluent. Wile et al. (1983) also found that sludge accumulated in the upper reaches of a marsh without some pretreatment. In spite of these precautions, dredging only over a 10- to 20-year period may be necessary due to soil buildup (Waste and Water International 1982).

In summary, constructed wetlands have been demonstrated to be an effective means of removing nutrients and other pollutants from applied wastewater. Because they can be constructed virtually in any location adjacent to an existing wastewater treatment plant, these wetland systems appear to be an attractive alternative in situations requiring advanced treatment of treated wastewater. Possible constraints to the use of artificial wetlands must still be considered. The range of experimental systems have produced a range of data results. As additional data become available concerning newly constructed wetland waste treatment systems, these issues will be clarified. Nevertheless, the use of these types wetlands to treat wastewater appears to have excellent potential.

3.8 Issue Category VIII: Mitigation

In the broadest sense, mitigation is taken to mean prevention or reduction of potentially adverse effects on a biological, socioeconomic, or political environment by proper design and implementation of a project. The regulations for implementing the procedural provisions of the National Environmental Policy Act (NEPA), issued by the Council on Environmental Quality (CEQ; 40 CFR Parts 1500-1508), define mitigation to include the following actions:

- Avoiding the impact altogether by not taking a certain action or parts of an action;
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation;
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;

- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and
- Compensating for the impact by replacing or providing substitute resources or environments.

This definition includes prevention, minimization, and reconstruction or replacement actions. Mitigation needs for fish and wildlife populations, their habitats, and human use of these resources are described in the mitigation policy developed by USFWS for its personnel (Federal Register 46(15): 7644-7663). The regulations issued by CEQ require that USFWS recommendations for mitigation developed under the Fish and Wildlife Coordination Act (FWCA; 16 USC 661 et. seq.) be integrated into all draft environmental impact statements. The policy also is intended to aid other Federal agencies and developers to anticipate the type of mitigation required. Additional FWCA mitigation regulations are expected to be developed by USFWS personnel to provide guidance for all federal agencies to comply with the Act. USFWS recommendations are to be based on habitat values lost, rather than specific acreages or populations of organisms, and the degree of mitigation recommended is to correspond to the value and scarcity of that habitat. Mitigation of impacts on threatened and endangered species is to be considered in addition to the requirements under the FWCA.

Wetlands in general are considered to be valuable habitats because: (1) they are relatively scarce; (2) they frequently contain an abundance of unique or rare species; (3) they are highly productive and diverse ecosystems which frequently form an integral part of a larger inter-connected floodplain system; and (4) they protect the floodplain against possible flood damage by acting as recharge areas. A project that uses wetlands or that presents a potential for adverse impacts to wetlands is likely to require more mitigation measures than a project in a different habitat.

Wastewater treatment plants typically discharge to a surface water body, and therefore are located near streams or lakes. Such facilities typically are sited on the largest area of flat land available near a river or stream, which frequently is in the floodplain. Because treatment facilities proposed in USEPA Region V are sited on floodplains, a summary of measures available to mitigate construction impacts and operation of wastewater treatment facilities would be helpful for design and review purposes. Such a document would ensure that all major impacts and the appropriate mitigations for each would be considered.

The following mitigative measures were identified by USEPA for consideration in the Phase II study:

- Mitigative measures to alleviate the primary impacts associated with the construction of a wastewater treatment facility and/or interceptor in a wetland;
- Mitigative measures to minimize the secondary impacts on wetlands from the construction of such facilities; and
- Mitigative measures to ensure, to the greatest extent possible, the environmental compatibility of discharges of treated wastewater with natural wetland ecosystems and to minimize potentially adverse effects on those systems.

Regulation of effluent discharge rate, timing of discharge (daily, seasonally) and control of the chemical content of the discharge would also be classified as mitigation, since suitable management of these factors would serve to minimize impacts. This type of mitigation would be particularly effective over the long term, since wetlands might generally experience gradual changes over time. A wetland receiving wastewater could change, for example, from an acid bog to a more alkaline cattail marsh. Nutrients will also eventually build up in the wetland soils, even with careful effluent control.

Many procedures have been developed for assessing habitat values and planning of mitigation measures for large-scale water projects. Most of these methods are summarized in the proceedings of a recent national workshop on mitigating losses of fish and wildlife habitats (Swanson 1979). However, the sessions on inland wetlands dealt primarily with habitat evaluation methods for such areas, rather than with mitigation. No information was presented specifically on wastewater treatment facilities, although some of the information on transportation and on siting of energy generation facilities is applicable.

Recent documents prepared by or for federal and state agencies also contain information on mitigating impacts on wetlands. These include a user's manual for estimation of the ecological effects of highway fill on wetlands (Shuldiner at al. 1979) and a report on the impacts of pipeline construction on stream and wetland environments (Crabtree et al. 1978). The former contains mitigation recommendations applicable to construction activities. The latter provides guidance on mitigation of the effects of pipeline construction in and adjacent to wetlands, and would be applicable to the construction of interceptors. The most comprehensive summary of potential impacts of construction activities in wetlands is that prepared by Darnell (1976). Many references on assessment of impacts on wetlands and evaluation of wetland habitats are cited in these documents.

Mitigation measures specifically designed to minimize impacts of the discharge of wastewater effluent to a wetland have not been published. However, considerations to be taken into account when designing such a system are included in Appendix B. Blumer (1978) described ways of increasing nutrient retention of restored wetlands in Florida. Structural diversity, flow patterns, multiple-use opportunities, and the use of water level control and filter structures were recommended on the basis of two years of studies on the Brookhaven National Laboratory, Upton New York, constructed wetland treatment systems. Implementation of these recommendations would mitigate the impacts of erosion, increase treatment effectiveness, and enhance wildlife habitat.

3.9 Issue Category IX: Legal, Administrative, and Regulatory Considerations

The growing concern for the future of wetlands has led to numerous Federal, state, and local laws and regulations to protect and preserve these areas. Communities that consider the use of wetlands as part of a wastewater treatment system are confronted with an array of legal considerations. While these considerations vary, several concerns exist for communities considering such a use for wetland areas. These concerns result from stipulations of the Federal Clean Water Act, two Executive Orders, and certain precedents being established within the states. This section presents a broad overview of these legal and regulatory concerns. A more detailed discussion of the regulatory issues will be presented in the Phase II study.

3.9.1 Federal Requirements

When most federal laws and policies for protection of wetland areas were adopted, multiple uses for wetlands were not considered. The regulations were adopted primarily to remove wetlands from development considerations and to discourage activity which could damage natural wetland areas. Because of this, the language of these regulatory programs often serves to inhibit the possible use of wetlands for multiple objectives. The concept that wetlands can be used to help treat municipal sewage thus represents a shift from the philosophy of complete protection. This shift in philosophy has implications for many of the original wetland regulations, and may be in conflict with certain aspects of these major policy requirements.

The Clean Water Act. The Clean Water Act provides broad statutory authority for protecting wetlands and other waters of the United States, and establishes an institutional framework for implementing wetland protection. This framework includes the Section 201 facility planning process, the Section 303 water quality standards process, the Section 402 National Pollutant Discharge Elimination System (NPDES) permit program, and the Section 404 Dredge and Fill permit program. The facilities planning process provides for a detailed review of the impacts of wastewater treatment projects on sensitive environmental resources, while the water quality standards establish limits on pollutants in the waters of the United States. However, primary protection of wetlands is implemented through the 404 permit program and the NPDES permit program.

The Section 404 permit is intended to prevent the destruction or alteration of wetlands by regulating activities which result in the disposal of dredged or fill materials in wetland areas. While the 404 permit protects wetland areas, it is actually a regulation of dredge and fill activities. If there is no placement of dredge or fill material, no permit is needed. Thus, this permit program would not apply to the creation of artificial wetlands or to the discharge of effluents to an existing wetland. A 404 permit could be necessary, however, if the treatment system required dredging activities in natural wetlands or if outfall devices were to be constructed in a wetland.

Under Section 402 of the Clean Water Act, the discharge of effluents directly to the navigable waters of the U.S. requires an NPDES permit and a program to monitor the discharge. Under this Act, most municipal treatment facilities must provide wastewater treatment at secondary or higher levels. When an artificial wetland is created to provide part of this treatment, a single discharge pipe is usually built from the artificial wetland to the receiving waters. Permit conditions are written to regulate the actual discharge of effluents. If a natural wetland is used, it may be extremely difficult to determine where the wetland begins and the "receiving waters" end. This problem is caused by uncertainties in the determination of wetland boundaries and hydrologic connections of wetlands with surface water and groundwater sources. In the case of a natural wetland it may be difficult to prepare an NPDES permit as a result. Monitoring requirements are affected for the same types of reasons. Determinations must be made concerning how the effluents being discharged will be regulated and how the discharge will be monitored.

Allowing wastewater to be discharged to a natural wetland may require certain changes in the Clean Water Act and the NPDES program (Rosencovitch 1983). The changes could include provisions similar to those of Section 301 (b) of the Act, which allows secondary treatment waivers for ocean discharges; or Section 318, which allows the discharge of certain pollutants, under controlled conditions, for certain projects. Altering the Clean Water Act to allow for special permit considerations for wetland treatment systems would offer greater flexibility to the communities involved, and could provide an economical yet effective method of treatment.

Executive Order 11990, Protection of Wetlands. Under Executive Order 11990, actions taken by federal agencies must minimize the degradation of wetlands and must preserve and enhance the natural and beneficial values of wetland areas. For communities wishing to use natural wetlands as part of their wastewater treatment systems, this Executive Order presents the issue of what constitutes "degradation." Certain interpretations of the Order have held that the mandate not only prohibits the use of a natural wetland as part of a wastewater treatment system, but that it also restricts the discharge of fully treated effluents to wetland areas, except under special situations.

This interpretation is subject to question, however. Some agree that in many cases the addition of nutrients actually enhances rather than degrades the natural wetland. The question of what determines "degradation" thus remains partially unresolved.

Executive Order 11988, Floodplain Management. The use of wetlands to treat municipal wastewater presents additional concerns when considered under the directives of Executive Order 11988, which requires federal agencies to avoid any direct or indirect support of floodplain development. The Order also directs federal agencies to provide leadership in acting to: (1) reduce the risk of losses due to flooding; (2) minimize the impact of floods on human safety and health; and (3) preserve the beneficial value of floodplains. Many natural wetlands are located within the 100-year floodplain, as are many areas that communities might consider suitable for the development of artificial wetlands.

It has not yet been determined whether USEPA or other federal funding sources, by encouraging wetland treatment systems, may be directly supporting floodplain development, thereby supports goals which are in conflict with Executive Order 11988. In addition, wetland treatment systems may not lend themselves to conventional methods of flood-proofing. Where wetlands are used for treatment, flooding situations may result in damage to the treatment system, short circuiting of discharges, or similar flood related problems for the community.

3.9.2 State and Local Requirements

Wetland areas are also protected under a variety of state and local regulations that may inhibit their use as part of wastewater treatment systems. Individual state statutes frequently address water quality, floodplain development, and wetlands protection. Language in an approved Coastal Zone Management Plan may prohibit wetland treatment systems on the coastal areas of Region V states. Local regulations may protect wetlands through zoning regulations, subdivision restrictions, building codes, sanitation codes, conservation districts, or special-use permit regulations. Deed restrictions may also exist for individual sites.

The majority of states have no regulations or guidelines addressing the use of wetlands for treatment of wastewater. In Florida and Michigan, however, such regulations have been initiated.

The State of Florida has adopted regulations that permit the experimental use of wetlands for low-energy water and wastewater recycling (Florida Department of Environmental Regulation 1979). In Michigan, a special-use permit has been issued by the Department of Natural Resources to allow the Roscommon County Department of Public Works to construct and operate the portion of the Houghton Lake wetland treatment site that is located on state-owned land. The site is under the joint jurisdiction of the Michigan Department of Natural Resources and the U.S. Fish and Wildlife Service.

While these state efforts represent recognition of a growing area of interest and concern, little has been done in other areas to develop regulatory criteria or guidelines to direct planning efforts for wastewater disposal or treatment in wetlands. The legal and administrative framework for protecting wetlands is well established; what is now needed is a reassessment of policy interpretations and regulatory issues to address the concept of multiple uses for wetland areas.

3.9.3 Administrative Review/Conflict Resolution

Use of wetlands either as a point of discharge for wastewater or as a means of advanced treatment, poses certain types of conflicts between involved Federal and state agencies. These conflicts arise due to the potential adverse effects of wastewater on wetlands and the responsibility of the agencies under the law to protect wetlands from degration. Federal agencies are charged with protection of wetlands under the various laws discussed above. In granting NPDES permits involving wetlands, for example, USEPA must resolve issues regarding possible degradation of natural wetland values as defined by reviewing agencies such as the USFWS. Currently no specific means of conflict resolution exists other than the method outlined below. Such a means must be developed however, if effective conflict resolution is to be achieved in these particular cases.

Reed and Kubiak (1983) proposed a review process for use by administrative agencies for evaluating the suitability of proposed discharges of wastewater to wetlands. This approach was developed for use within the context of the existing "201" facilities planning process. Because it represents the only published attempt to date that concerns the integration of legal, regulatory, and administrative constraints into the process of selecting a wetland discharge or treatment alternative, the approach is briefly outlined here.

The detailed methodology proposed by Reed and Kubiak (1983) for determining suitability of a wetland for wastewater treatment or discharge is shown in Figure 3.9-1. The method provides a means of determining discharge suitability early in the planning process, and is based on the requirements of the water quality standards process and limitations specified in Section 402 permit procedures.

The initial step in this method is to apply appropriate screening criteria to determine the quantity and quality of effluent discharged as well as the cost effectiveness of the wetland alternative. If following the initial screening a natural wetland alternative is not determined to be feasible, feasibility of other modes of discharge (to surface water or groundwater) need to be identified. If an artificial wetland is determined to be feasible, the impacts on the ultimate receiving water must be determined in relation to existing water quality limitations, just as in the case of a conventional discharge. In some cases water quality limitations may prevent use of an artificial system (Figure 3.9-1).

If a natural wetland is determined to be feasible, then an evaluation should be conducted to determine if this alternative is compatible with water quality standards and to determine if adverse impacts to the wetland would result (Figure 3.9-1). This evaluation should precede the decision concerning use of a natural wetland for wastewater application. Use of a natural wetland alternative may not be feasible if it is determined that such an alternative is incompatible with the maintenance high water quality standards in a particular receiving stream, for example. In other cases it may be determined that water quality will not be degraded significantly by the natural wetland alternative, and that it thus constitutes a feasible alternative

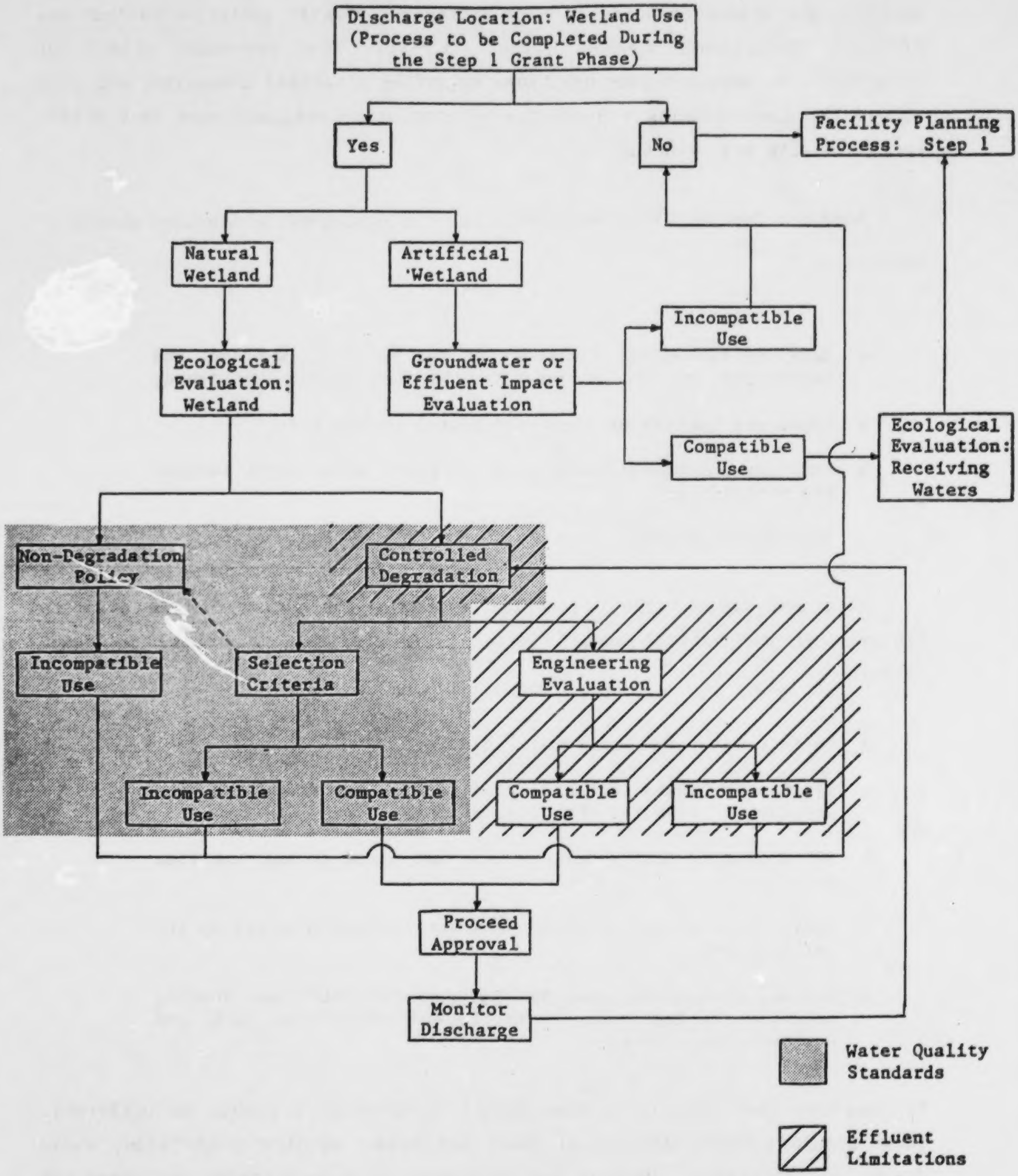

Discharge Location: Wetland Use (Process to be Completed During the Step 1 Grant Phase)
Yes
No
Facility Planning Process: Step 1
Natural Wetland
Artificial Wetland
Ecological Evaluation: Wetland
Groundwater or Effluent Impact Evaluation
Incompatible Use
Compatible Use
Ecological Evaluation: Receiving Waters
Non-Degradation Policy
Controlled Degradation
Incompatible Use
Selection Criteria
Engineering Evaluation
Incompatible Use
Compatible Use
Compatible Use
Incompatible Use
Proceed Approval
Monitor Discharge
Water Quality Standards
Effluent Limitations

Figure 3.9-1. Facility planning assessment process incorporating wetland use alternative, as designed by Reed and Kubiak (1983).

(Figure 3.9-1) as a regulated ("controlled degradation or enhancement") discharge. The discharge needs to meet criteria for water quality standards and effluent limitations, however (Figure 3.9-1). This procedure allows for flexibility in making permit decisions regarding a wetland discharge, and also allows for discontinuing a discharge if monitoring programs show that detrimental impacts are occuring.

Reed and Kubiak (1983) concluded that the ecological evaluation should determine:

- Existing ecological functions of the receiving wetland, and importance of the wetland to the surrounding watershed;
- Types and quality of plant and animal communities;
- Existing government management programs which might involve the wetland; and
- Existing regulatory programs which apply to the wetland.

Reed and Kubiak (1983) reported that the evaluation of the existing features of the wetland should include characterizations of the following factors:

- Surface water and groundwater quality;
- Hydrologic regime (especially storm flow characteristics and groundwater recharge characteristics);
- Flood control and water storage and yield during low flow periods.
- Shoreline erosion protection characteristics provided by the wetland; and
- Overall ecological quality (species diversity and health; potential recreational, research, and educational uses; and socioeconomic values).

To complete the evaluation, appropriate field studies should be performed. These should include measures of plant and animal species composition, abundance, and diversity. Methods for performing such inventories are presented in Reed and Kubiak (1983) and in Section 2.8 of Appendix A (the Technical Support Document). The results of the ecological evaluation can be used during the course of the facility planning process to provide a detailed basis for determining potential impacts on the receiving wetland, for establishing and the acceptability of the discharge to resource managers and involved review or permitting agencies.

4.0 INVENTORY OF WASTEWATER DISCHARGES TO WETLANDS IN REGION V

The inventory presented in this section describes wastewater discharges to wetlands in USEPA Region V, and was conducted from October through December 1980, with the assistance of state agencies, local officials, individual treatment plant operators, and several facility planning firms. The most current data available for the treatment facilities and wetlands in Region V were compiled and incorporated into this report. A number of types of facilities and wastewater discharges were identified during this inventory, and included wastewater treatment plants, water treatment plants, industrial facilities, creameries, state parks and camps, mobile home parks, commercial facilities such as truck stops and motels, and institutions such as schools, correctional centers, and nursing homes.

Initially, only municipal treatment facilities were to be included in the inventory. However, some industrial facilities were also included because of the possibility that certain issues (such as the effects due to trace metals) could be studied more easily at those sites, since concentrations of trace metals and other substances of interest typically are higher in discharges from industrial facilities than in municipal discharges. Industrial facilities were also determined to be of value for investigation because of their high frequency in Region V states, and the likelihood that many could discharge to wetlands.

4.1 Identification of Dischargers

4.1.1 Data Collection

Personnel at each of the following agencies were contacted and requested to provide a list of known wetland discharge sites in that state:

- Illinois Environmental Protection Agency;
- Indiana State Board of Health;
- Michigan Department of Natural Resources;

- Minnesota Pollution Control Agency;
- Ohio Environmental Protection Agency; and
- Wisconsin Department of Natural Resources.

With the exception of Wisconsin, which maintained a list of discharges to wetlands from municipal facilities only, none of the states had prepared such a list. The task of compiling a list of these sites therefore required additional consultation among knowledgeable personnel in the remaining states. The structure and organization of agency files in these states precluded identification of such sites by an overview process. It was not possible for project investigators to examine the extensive amount of data for all permitted facilities in each state. Also, information on the types of land cover (i.e., wetland versus some other ecosystem type) between the treatment facility and the final discharge point typically was not recorded. Following examination of the initial lists of potential sites compiled by state agency personnel, visits were made to all states. The following information was obtained by examination of files for potential sites at which wetlands were identified:

- Name of treatment plant operator and/or local contact;
- Receiving stream classification;
- Map and photographs (if available);
- Survey reports;
- Public notices of intent; and
- Current or annual summary discharge monitoring report forms.

Facility plans for all plants were not examined. It was anticipated that the overview information obtained from agency files, in combination with the information to be received from questionnaires distributed to the treatment plant operators (Section 4.1.2) would be sufficient for a preliminary identification of both the major characteristics of the discharge and the types of wetlands receiving the discharge. A total of 161 facilities were identified as possibly having wetland discharges and are listed in Table 4.1-1.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

STATE/FACILITY	Survey Form Not Sent 1	Form or Call Returned 2	Site Visited 3	Discharges to Lake/Stream 4	Underground/On-land Discharge 5	Discharge Never Occurred 6	Discharge Not Observed 7	Effluent Pumped to Other Facility 8	Discharge to Wetland Ceased 9	Non-wastewater Discharge 10	Unintentional Discharge to Wetland 11	Discharges to Man-modified Wetland 12	Discharges to Natural Wetland 13
ILLINOIS													
Atwood Vacuum Machine Company		x		x									
Dallas Wastewater Treatment Facilities		x		x									
Erie Wastewater Treatment Plant		x										x	
Farmingdale Wastewater Treatment Plant			x										x
Frantz Manufacturing Company		x		x									
Harrisburg Wastewater Treatment Plant		x		x									
Ipsen Industries and Alco Standard Company		x											x
Moline Consumers Company		x							x				
Pere Marquette State Park													x[1]
Sterling Steel Ball Corporation		x		x									
Stockton Processing Company		x			x					C			
US Penitentiary - Marion		x						x	x				
Vienna Correctional Center		x										x	
West Chicago Sewage Treatment Plant		x		x									
Winfield Wastewater Treatment Plant		x	x										x
TOTAL (15 facilities)	0	13	2	6	1	0	0	1	2	1	0	2	4
INDIANA													
Angola Sewage Treatment Plant		x	x										x
Angola Union 76-69 Truck Plaza		x	x										x
Avilla Wastewater Treatment Facility			x				x						
Culver Wastewater Treatment Plant		x	x									x	
Fremont Sewage Treatment Plant		x	x										x
Gentner Packing, Inc.			x									x	
Kendallville Wastewater Treatment Plant		x	x										x

C = Cooling water.

[1] Information from agency files only.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

	1 Survey Form Not Sent	2 Form or Call Returned	3 Site Visited	4 Discharges to Lake/Stream	5 Underground/On-land Discharge	6 Discharge Never Occurred	7 Discharge Not Observed	8 Effluent Pumped to Other Facility	9 Discharge to Wetland Ceased	10 Non-wastewater Discharge	11 Unintentional Discharge to Wetland	12 Discharges to Man-modified Wetland	13 Discharges to Natural Wetland
INDIANA (continued)													
L and K Motel			x									x	
Moore's Business Forms		x						x		S			
North Webster Wastewater Treatment Plant		x		x									
Silver Lake Mobile Home Park			x										x
Union 76 Truck Stop - Center Valley	x												
Weatherhead Company		x	x										x
TOTAL (13 facilities)	1	8	10	1	0	0	1	1	0	1	0	3	6
MICHIGAN													
Bellaire Wastewater Treatment Plant		x	x						x				
Clark Township	x										x		
Crystal Falls	x										x		
Decatur	x		x										x
Edmore	x										x		
Grayling	x		x										x
Houghton Lake Wastewater Treatment Plant		x	x										x
Kinross (Kincheloe AFB)		x	x										x
Marion	x		x										x
Onekama	x				x								
Roscommon	x		x										x
Schuss Mountain	x		x		x								
TOTAL (12 facilities)	9	3	7	0	2	0	0	0	0	0	3	1	6

C = Cooling water.
S = Stormwater.
[1] Information from agency files only.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

	Survey Form Not Sent 1	Form or Call Returned 2	Site Visited 3	Discharges to Lake/Stream 4	Underground/On-land Discharge 5	Discharge Never Occurred 6	Discharge Not Observed 7	Effluent Pumped to Other Facility 8	Discharge to Wetland Ceased 9	Non-wastewater Discharge 10	Unintentional Discharge to Wetland 11	Discharges to Man-modified Wetland 12	Discharges to Natural Wetland 13
MINNESOTA													
AaCron, Inc.										C[1]			
Alexandria Lake Area Sanitary District		x											x
Alexandria Light and Power Company		x											x
Barry Wastewater Treatment Plant		x	x										x
Battle Lake Wastewater Treatment Plant		x	x										x
Brandon Wastewater Treatment Plant		x	x										x
Brandon Water Treatment Plant			x				x						
Camp Joseph Austin	x				x								
Clinton Wastewater Treatment Plant		x	x						x		x		
Dalton Wastewater Treatment Plant													x[1]
Dayton Development Company		x	x										x
Detroit Lakes Wastewater Treatment Plant		x											x
Donnelly Water Treatment Plant		x											x
Elbow Lake Water Treatment Plant		x		x									
Elmdale Creamery Association			x										x
Erie Mining Company		x							x				
Flensburg Wastewater Treatment Plant				x[1]									
Foley Wastewater Treatment Plant	x			x									
Hampton Wastewater Treatment Plant		x										x	
Hanska Meats		x						x		C			
Hardwick Wastewater Treatment Plant		x		x									
Hermantown School District #700		x											x
Hitterdal Wastewater Treatment Plant		x										x	
Ida Township	x							x					
Ironton Water Treatment Plant		x											x
Isle Wastewater Treatment Plant													x[1]

C = Cooling water.

[1] Information from agency files only.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

MINNESOTA (continued)	1 Survey Form Not Sent	2 Form or Call Returned	3 Site Visited	4 Discharges to Lake/Stream	5 Underground/On-land Discharge	6 Discharge Never Occurred	7 Discharge Not Observed	8 Effluent Pumped to Other Facility	9 Discharge to Wetland Ceased	10 Non-wastewater Discharge	11 Unintentional Discharge to Wetland	12 Discharges to Man-modified Wetland	13 Discharges to Natural Wetland
Itasca Nursing Home									x[1]				
Jeno's Wilderness Lodge	x												
Kensington Wastewater Treatment Plant		x	x										x
La Grand Township	x							x					
Lake Mary Township	x							x					
Lake Park Water Treatment Plant		x											x
Land O'Lakes Company			x					x					
Lewiston Wastewater Treatment Plant		x											x
Longville Wastewater Treatment Plant													x[1]
Loretto Wastewater Treatment Plant		x									x		
Maple Hills Estates Mobile Home Park			x									x	
Menahga Wastewater Treatment Plant		x	x										x
Midland Glass Company										C[1]			
Miltona Wastewater Treatment Plant		x											x
Minnesota DNR - Hennepin State Park						x[1]							
Minnesota DNR - Lake Carlos State Park								x[1]					
Minnesota DNR - Sibley State Park		x				x							
Minnesota Lake Wastewater Treatment Plant													x[1]
Northome Wastewater Treatment Plant	x						x						x
Nelson Creamery Association		x						x		C			
Orono Wastewater Treatment Plant (MWCC)	x												
Pequot Lakes Wastewater Treatment Plant	x								x				
Petham Wastewater Treatment Plant		x	x										x
Ramey Farmers Co-op Creamery Association		x	x										x
Reynolds Cooperative Creamery Association		x										x	
Rose Co-op Creamery													x[1]
St. James Wastewater Treatment Plant	x			x									

C = Cooling water.

[1] Information from agency files only.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

	Survey Form Not Sent 1	Form or Call Returned 2	Site Visited 3	Discharges to Lake/Stream 4	Underground/On-land Discharge 5	Discharge Never Occurred 6	Discharge Not Observed 7	Effluent Pumped to Other Facility 8	Discharge to Wetland Ceased 9	Non-wastewater Discharge 10	Unintentional Discharge to Wetland 11	Discharges to Man-modified Wetland 12	Discharges to Natural Wetland 13
MINNESOTA (continued)													
St. Joseph Wastewater Treatment Plant		x	x										x
Shafer Wastewater Treatment Plant		x	x										x
South International Falls WWTP		x		x									
Staples Wastewater Treatment Plant		x	x										x
Sunburg Co-op Creamery Association													x[1]
Taconite Wastewater Treatment Plant		x										x	
Twelve-Hi Mobile Home Estates	x			x									
Union Creamery Association										C[1]			
Upsala Wastewater Treatment Plant													x[1]
Vergas Wastewater Treatment Plant	x					x							
Vineland, Mille Lacs Indian Reservation	x												
Wadena Air Force Station	x				x								
Wahkon Wastewater Treatment Plant			x										x
Wahkon Bay Mobile Home Park			x					x	x				
Winton Wastewater Treatment Plant		x											x
Youth Opportunities Unlimited	x				x								
TOTAL (68 facilities)	14	34	18	7	3	3	1	8	6	5	2	5	30
OHIO													
Beulah Beach	x												
Gambier Wastewater Treatment Plant			x									x	
Hinde Subdivision			x										x
Uniroyal Inc., Erie Industrial Park			x										x
TOTAL (4 facilities)	1	0	3	0	0	0	0	0	0	0	0	1	2

C = Cooling water.

[1] Information from agency files only.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

	Survey Form Not Sent 1	Form or Call Returned 2	Site Visited 3	Discharges to Lake/Stream 4	Underground/On-land Discharge 5	Discharge Never Occurred 6	Discharge Not Observed 7	Effluent Pumped to Other Facility 8	Discharge to Wetland Ceased 9	Non-wastewater Discharge 10	Unintentional Discharge to Wetland 11	Discharges to Man-modified Wetland 12	Discharges to Natural Wetland 13
WISCONSIN													
Advance Transformers Co.				x						C[1]			
Amani Sanitary District													x[1]
Amron Corporation			x					x	x				
Arcadia Wastewater Treatment Plant			x										x
Associated Milk Products, Inc.			x										x
Brillion Wastewater Treatment Plant		x											x
Chili Sanitary District		x											x
Clayton Municipal				x[1]									
Curtiss Wastewater Treatment Plant		x											x
Dresser Wastewater Treatment Plant												x[1]	
Drummond Sanitary District		x											x
Elk Mound Water and Sewer Utility		x											x
Florence Municipal Sewer System													x[1]
Gilson Brothers Company		x	x										x
Hayssen Manufacturing Company										C[1]			
Hillshire Farms Company		x	x									x	
Kasson Cheese Company, Inc.													x[1]
Lakeside Cheese Factory			x										x
Menasha Corporation		x											x
Milltown Sewage Treatment Plant			x				x						x
Minong Wastewater Treatment Plant		x	x		x						x		
Mobil Oil Corporation		x		x									
Muskego NE District Sewage Treatment Plant												x[1]	
Muskego Sewage Lagoons								x[1]					

C = Cooling water.

[1] Information from agency files only.

Table 4.1-1. Status of facilities believed to discharge wastewater to wetlands in USEPA Region V. Data are current as of December 1980.

	Survey Form Not Sent	Form or Call Returned	Site Visited	Discharges to Lake/Stream	Underground/On-land Discharge	Discharge Never Occurred	Discharge Not Observed	Effluent Pumped to Other Facility	Discharge to Wetland Ceased	Non-wastewater Discharge	Unintentional Discharge to Wetland	Discharges to Man-modified Wetland	Discharges to Natural Wetland
WISCONSIN (continued)	1	2	3	4	5	6	7	8	9	10	11	12	13
New Auburn Wastewater Treatment Plant													x[1]
Northernaire Lake Terrace		x											x
Oconomowoc Electroplating Company		x											x
Ogema Sanitary District #1													x[1]
Paddock Lake Wastewater Treatment Plant	x						x						x
Pence Wastewater Treatment Plant		x											x
Phelps Sanitary District		x											x
Radisson Sewage Treatment Plant		x											x
Rockland Sanitary District		x											x
Seeger's Dairy, Inc.		x											x
Shawano County Health Care Facility			x										x
Sherwood Wastewater Treatment Plant		x											x
Siren Wastewater Treatment Plant			x										x
Stockbridge Sanitary District		x	x										x
Three Lakes Sanitary District		x											x
Tony Sewage Treatment Plant		x											x
Turtle Lake Wastewater Treatment Plant		x	x										x
Vitamin Products Company		x						x	x				
Whitehall Wastewater Treatment Plant		x	x										x
Whitewater Wastewater Treatment Plant		x											x
Wisconsin DH&SS - Flambeau State Camp		x							x				
Wisconsin DNR - Peninsula State Park		x											x
Zimmerman Mink Food Plant		x							x				
TOTAL (47 facilities)	0	28	13	4	1	0	1	3	4	2	1	3	33
TOTAL FOR USEPA REGION V STATES (159 facilities)	25	86	53	18	7	3	3	13	12	9	6	15	81

4.1.2 Discharger Questionnaire

The information from agency files was reviewed prior to mailing a brief questionnaire to the treatment plant operator or other appropriate contact at each facility. Questionnaires were mailed to all facilities identified except for those not recommended for such mailing by state agency personnel.

Approximately 55% of the facilities surveyed responded by telephone call or letter. In several instances, the engineering firm that had designed the facility was requested to respond. Three weeks after the mailing date, telephone calls were initiated to those facilities that showed the highest priority for future study, based on available information. Not all non-responding facilities could be contacted, due to restrictions on available time and finances. All pertinent information contained in each returned survey form was added to the data base previously obtained for that facility.

4.1.3 Preliminary Site Surveys

Because the study was initiated in autumn it was necessary to complete visits to as many sites as possible prior to the onset of winter, a brief qualitative survey was initiated in mid-November of 1980. The sites selected for field investigation were identified on the basis of the agency file data and the responses obtained. The sites of interest were determined to be those intermediate between the following two categories: (1) those sites at which research currently was being performed or at which detailed field investigations were known to have been performed; and (2) those sites considered to be too small or otherwise not suitable for inclusion in the research to be performed during the full-scale study.

The following criteria were used to select sites for the preliminary field survey:

- State in which discharge was located (known sites in Michigan had already been visited by one member of the research team; all remaining states were visited);

- Type of facility (municipal, industrial, other);
- Type of receiving wetland (forest, marsh, bog, etc.);
- Characteristics of discharge (chlorinated, trace metals present, etc.);
- Length of time discharge had occurred;
- Relative wildlife value of receiving wetland (based on information available);
- Volume of discharge;
- Presence of other discharges into wetland (single discharges preferred);
- Surrounding land use (if known);
- Geographic location (a broad range of latitudes was used); and
- Amount of data available.

Thirty-eight sites were selected and visited: 16 in Minnesota, 10 in Wisconsin, 1 in Illinois, 9 in Indiana, and 2 in Ohio. The Minnesota sites and six of the Wisconsin sites were visited between 16 November and 26 November 1980. The Indiana and Ohio sites were visited between 1 and 6 December 1980, and the remaining four sites in Wisconsin were visited between 26 December 1980 and 2 January 1981.

At each site, qualitative observations were made as to the nature and extent of the receiving wetland. A map was prepared of the area around the discharge point to show the nature of the drainage basin receiving the effluent, and where possible, the point at which the wetland receiving the discharge was connected to other bodies of water such as sloughs, streams, rivers, or lakes. The treatment plant operator was contacted (where possible) to obtain additional information on each site.

During the surveillance of each site, the area around the discharge point, the receiving wetland, and other water bodies were examined. Records of the approximate areal extent of the wetland, the nature and condition of the dominant vegetation, the distribution of the vegetation relative to the discharge, and the estimated wildlife value of the receiving wetland and surrounding area were made. Photographs were taken at each site for future reference and to assist in summarizing the survey results. Observations were made of the surrounding land uses, the presence of any additional discharges, and the accessibility of the site.

Accessibility was used as an important criterion for estimating the potential value of particular wetlands surveyed for inclusion in the future full-scale studies. For purposes of this study, "accessibility" is defined as both the ease with which the site could be reached by car and the relative ease with which specific points within the wetland could be sampled. For example, the Staples, Minnesota, site was given an accessibility rating of "good" because there was easy access to the point where the discharge entered the marsh as well as to sites above and below the discharge. Similarly, the Angola, Indiana, site was rated highly for accessibility, since sampling points above, in, and below the wetland could be reached easily. Accessibility is a significant factor in the selection of a study site because of the need to limit logistic difficulties during sampling.

4.2 Results of the Inventory

The sites identified by state agency personnel as possible wetland discharge sites were listed in Table 4.1-1. Of the 161 facilities, 99 (60%) discharged to wetlands. The other facilities were eliminated for the reasons indicated by the column headings in Table 4.1-1 (i.e., discharge had ceased, routed to other facility or another surface water body, etc.). Fifteen facilities discharged to wetlands that had been modified as follows:

- Diking;
- Damming;
- Excavation;
- Impoundment;
- Partial drainage; or
- Formation of wetland after discharge began.

Facilities with discharges of wastewater to natural wetlands are included in Column 13 of Table 4.1-1. Facilities with non-wastewater discharges, such as cooling water or stormwater runoff (Column 10), and facilities with unintentional discharges caused by seepage or leakage from improperly working equipment or poor facility design (Column 11) were eliminated.

4.2.1 Wastewater Discharges to Natural Wetlands

All facilities positively identified in the inventory as discharging to a wetland are listed in Table 4.2-1 and shown on Figures 4.2-1 through 4.2-6. A summary of these sites by type of facility is presented in Table 4.2-2. On a region-wide basis, 76% of the 98 discharges to wetlands were from municipal facilities, 17% were from commercial facilities, and 6% were from a variety of other types of facilities. The distinction between major and minor municipal facilities is not shown in Table 4.2-2 because only two facilities in Minnesota were designated as major municipals in the state pollution control agency files. Although state parks are classified as industrial facilities by the State of Minnesota and as municipal facilities by the State of Illinois, these have been given the designation of "Other" in Table 4.2-2 to be consistent with designations for similar sites in other states.

General information used to identify the potential for each facility for further study is also presented in Table 4.2-1. The operational date is the year in which the facility was constructed. The number of years of discharge indicates how long the facility actually has discharged to the wetland area, and is not necessarily equal to the number of years of operation. Information on any additional types of discharges (e.g., stormwater runoff, cooling water, process water, wash water) is included in the Significant Aspects/Comments column. The criteria used to determine the potential of a facility for further study are the same as those listed in Section 4.1.3. The sites not visited were also given a rating, if adequate information was available. This was a subjective judgement based on data from survey forms, telephone responses, state agency file descriptions, and maps and photographs prepared by state agencies.

Table 4.2-1 Facilities in USEPA Region V confirmed to have discharges of wastewater to wetlands.

ILLINOIS

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
1.	Village of Erie WWTP Erie (Whiteside)	M/2	1948/32	0.167	1	Slough	PEM1Bd	Wild., Rec., Fish	Low
2.	Farmingdale WWTP Lisle (DuPage)	M/2	-/10	0.190	30	Cattail-willow marsh	PEM1C PSS1C	Wild., Rec., Duck Facilities in poor condition Headwaters of Lily Cache Creek	High
3.	Ipsen Industries and Alco Standard Co. Cherry Valley (Boone)	I	1975/10	0.0005-0.001	2	Cattail marsh	PEM1D	Wild., Rec. S, SW discharges to ditch that enters marsh	Low
4.	Pere Marquette State Park Grafton (Jersey)	O/1	NA	0.020	NA	Seasonally flooded basin or flat	NA	Bottomland area tributary to Gilbert Lake	NA
5.	Vienna Correctional Center Vienna (Johnson)	M/3	1964/15	0.127	80	Wooded swamp	PAB2 PSS1 PFO1Ad	Wild., Duck, Fish Cl_2 discharge Old railway bed State-owned	High
6.	Winfield WWTP Winfield (DuPage)	M/2	1962/12	1.061	20	Marsh-fen	PEM1C	Wild., Duck Rare species of plants present Cl_2 discharge Owned by DuPage County Forest Preserve	High

KEY:

Type of Facility/Treatment

C - Commercial
I - Industrial
M - Municipal
O - Other

1 - Primary
2 - Secondary
3 - Tertiary

Significant Aspects/Comments

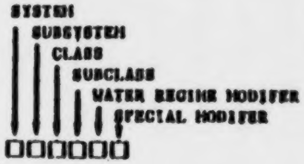
Crop - Crop production area
Duck - Waterfowl production area
Fish - Fish spawning area
Rec. - Area used for recreation
Wild - Wildlife habitat

Type of Discharge

CW - Cooling water
PW - Process water
S - Sanitary
SR - Stormwater runoff
WW - Wash water
Cl_2 - Chlorinated

NA - Insufficient information available

US FISH AND WILDLIFE SERVICE WETLAND CLASSIFICATION SCHEME



SYSTEM AND SUBSYSTEM

L Lacustrine
1 Littoral
P Palustrine
R Riverine
1 Intermittent

CLASS AND SUBCLASS

AB Aquatic Bed
1 Submergent
2 Floating-leaved
3 Floating
EM Emergent Wetland
1 Persistent
2 Non-persistent
FO Forested Wetland
1 Broad-leaved deciduous
2 Needle-leaved deciduous
3 Deciduous
4 Evergreen
5 Dead
ML Moss-Lichen Wetland
RS Rocky Shore
1 Bedrock
SS Shrub-Scrub Wetland
1 Deciduous
2 Evergreen
UB Unconsolidated Bottom

WATER REGIME

A Permanently flooded
B Intermittently flooded
C Semipermanently flooded
D Seasonally flooded
E Saturated
F Temporarily flooded
G Artificial (flooded only as a result of discharge)

SPECIAL MODIFIERS

a Acid soils
b Beavers
c Partially drained/ditched
d Diked/impounded
e Artificial

Table 4.2-1

INDIANA

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
1.	Angola STP Angola (Steuben)	M/2	1920s/60+	1.155	1-2+ forest	Cattail marsh Bottomland hardwood forest	PEM1D PSS PFO3	Wild., Duck Metals in discharge City owns entire area	High
2.	Angola Union 76-69 Truck Plaza Angola (Steuben)	0/2	1971/8	0.005-0.010	2-3	Cattail marsh	PEM1d	Metals and Cl_2 in discharge	Low
3.	Culver WWTP Culver (Fulton)	M+I/2	1952/28	0.450	100	Cattail-shrub marsh	PEM1Abd PSS	Man-modified (dammed) Duck, Wild. Complex area	Moderate
4.	Fremont STP Fremont (Steuben)	M+I/2	1957 & 1976/23	0.150	100-200	Cattail-shrub marsh	PAB2Ab PEM1 PSS	Rec., Wild., Fish, Duck Botulism has occurred State wetland conservation area	High
5.	Gentner Packing, Inc. South Bend (St. Joseph)	I/2	NA	0.650	Ditch runs 8-9 mi.	Bottomland hardwood forest-swamp	PFO1Fd	Discharge to Auten Ditch, then to swamp PW, CW discharges	Low
6.	Kendallville WWTP Kendallville (Noble)	M/2	1958/22	1.500	20	Lake with adjacent cattail marsh Wooded swamp	L1UB PEM1A PSS PFO1	Discharge is to Henderson Lake Wetland surrounds lake Cl_2 and P removal	High
7.	L & K Motel Angola (Steuben)	0	1971/9	0.012	0.06	Cattail marsh	PEM1d	Discharges to small creek, to small pond, to small wetland Metals and Cl_2 in discharge	Low
8.	Silver Lake Mobile Home Park Angola (Steuben)	0	1977/5	0.0044	10-20	Cattail-willow marsh	PEM1D PSS1	Good waterfowl habitat Marsh adjacent to Silver Lake Cl_2 discharge	Low
9.	Weatherhead Co. Angola (Steuben)	I/3	1968/12	0.133	30-40	Cattail-willow marsh Bottomland forest	PAB2A PEM1 PSS1 PFO	Wild., Rec. Wetland adjacent to Little Center Lake PW, CW, S, SW discharges	Low

Table 4.2-1

MICHIGAN

Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
1. Bellaire WWTP (Antrim)	M/2	1970/10	0.400	40	Wet meadow	PEM2A	Discharge diverted in 1981; could study recovery.	High
2. Decatur WWTP Decatur (Van Buren)	M	NA	NA	150	Cattail marsh Shrub border	PEM PSS	Rec., Duck, Wild.	High
3. Grayling WWTP Grayling (Crawford)	M/2	NA	NA	100	Cedar-alder hardwood forest	RFO	Dump adjacent to wetland	Low
4. Houghton Lake Houghton Lake (Roscommon and Missaukee)	M/2	1972 & 1978/3	1.000	600	Sedge-willow wet meadow	PML PEM PSS1Ad	Leatherleaf and bog birch present Entire area = 1,759 acres Peatland is state-owned but under USFWS control	High
5. Kinross WWTP (Kincheloe Air Force Base) Kinross (Chippewa)	M/2	1962-78/16 New Plant 1978/2	1.500 (Old) 0.040 (New)	700	Currently a Cattail marsh; converted from an acid bog due to alkaline discharge; ¼ of natural bog remained in 1981.	PEM1A	Former US Air Force base; presently state-owned Discharge to man-made ditch that enters wetland.	High
6. Marion WWTP Marion (Osceola)	M	1977/3	NA	20	Alder-willow swamp	LSS	Railroad gives defined outlet	High
7. Roscommon WWTP Roscommon (Roscommon)	M	NA	NA	5	Hardwood-cedar floodplain forest	RFO	Wild. Open flow observed in January Discharge flows to cattail ditch, then to wetland	High

Table 4.2-1

MINNESOTA

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
1.	Alexandria Lakes Area Sanitary District (ALASD) Alexandria (Douglas)	M+I/3	1977/3	1.200	1	Marsh	PEMA	Duck Heavy metals present in effluent	High
2.	Alexandria WTP #2 Light and Power Co. Alexandria (Douglas)	M	1959/20	0.060/week	4	Slough Cattail marsh	PEM1A	Duck City water supply Fe and Mn treatment PW, backwash discharge	Moderate
3.	Barry WWTP Barry (Big Stone)	M/1	1938/42	NA	10-20	Cattail marsh	PEM1D PSS	Rec., Wild. Existing marsh in Allen State Wildlife Management Area	Moderate
4.	Battle Lake WWTP Battle Lake (Otter Tail)	M/2	1952/28	0.079	2	Pothole Cattail marsh	PAB3A PEM1 PSS1	Rec., Wild., Duck Discharge to Slaughterhouse Slough scheduled to stop by 1985	Moderate
5.	Brandon WWTP Brandon (Douglas)	M/1	1956/24	0.042	1 mile long	Slough	PAB2,3 PEM1A	Wetland used as a junk yard Slough feeds into Whiskey Lake	Low
6.	Dalton WWTP Dalton (Otter Tail)	M/2	1971/-	0.034	NA	Land-locked slough	NA	Facility discharge questionable	NA
7.	Dayton Development Co. Ridgedale Center Minnetonka (Hennepin)	O/1	1973/7	0.330 (design)	45	Cattail-shrub marsh	PAB3A PEM1 PSS1,2	Wild., Rec., Duck SR discharge composed of 60% parking lot runoff and 40% undeveloped land runoff PW, CW, SR discharges	Low
8.	Detroit Lakes WWTP Detroit Lakes (Becker)	M/3	1923-41, 1963-77/50	1.000	200	Shallow lake Cattail marsh	NA	Rec., Wild., Duck Man-made channel	Moderate
9.	Donnelly WWTP Donnelly (Stevens)	M+I	1920/60	0.600	52	Slough Cattail marsh	R1AB1 PEM1	Wild., Rec. Discharge is to stream that enters Peterson's Slough PW, S discharges	High
10.	Elmdale Creamery Elmdale (Morrison)	I	NA	0.003	2	Pothole Cattail-sedge marsh	PEM1	PW, CW, S discharges	Low

Table 4.2-1

MINNESOTA (continued)

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
11.	Hampton WWTP Hampton (Dakota)	M/3	1957/23	0.040	1	Pothole	PAB1Ge	Cl_2 discharge Discharge scheduled to stop by 1985	Moderate
12.	Hermantown I.S.D. #700 Duluth (St. Louis)	C/3	1939/41	0.008	2	Wooded swamp	PFO3D	Discharge scheduled to stop by 1985	Low
13.	Hitterdal WWTP Hitterdal (Clay)	M/2	1962/18	0.039	15	Pond Cattail marsh	L1RS1B PEM1	Duck, Rec., Crop	Moderate
14.	Ironton WWTP Ironton (Crow Wing)	M/2	1963/17	0.050	20	Cattail marsh	PEM1	Discharge flows from marsh to another marsh, then to Blackhoff Lake	Moderate
15.	Isle WWTP Isle (Mille Lacs)	M+I/2	1971/9	NA	6-8 mi.	Shrub swamp	NA	NA	NA
16.	Kensington WWTP Kensington (Douglas)	M/2	1950/30	0.046	1-2	Pothole Cattail marsh	PEM1A	Scheduled to stop by 1985	Low
17.	Lake Park WTP Lake Park (Becker)	M/2	1929/51	0.017	10	Cattail-willow marsh	PEM1 PSS1	Mn and Fe treatment	Low
18.	Lewiston WWTP Lewiston (Winona)	M+I/2	1973/7	0.250	6.5	Natural dry run	NA	Scheduled to stop by 1985	Low
19.	Longville WWTP Longville (Cass)	M/2	1961/-	0.020	NA	Swamp	NA	NA	NA
20.	Maple Hills Estates Corcoran (Hennepin)	C	1971/-	0.030	10 (pond) 2-3	Pond Reed canary grass marsh	PEM1e	Discharge flows from ditch to Rush Creek to pond/marsh complex	Low
21.	Menahga WWTP Menahga (Wadena)	M/2	1952/28	0.058	20	Cattail marsh	PEM1	Marsh is 50 feet from Bueberry River	Low
22.	Miltona WWTP Miltona (Douglas)	M/2	1952/28	0.034	80	Marsh Wooded swamp	PML PEM1D PSS PFO3,4	Rec., Wild., Duck Bog-mat vegetation Discharge scheduled to stop by 1985	Moderate
23.	Minnesota Lake WWTP Minnesota Lake (Fairbault)	M	1951/-	0.134	NA	Cattail-sedge marsh Slough	PEM1	Rec., Wild., Slough-State wildlife management area 8 species of native Minnesota birds nest in marsh and slough 3 landfill sites around marsh (cement, wood, solid waste debris)	High
24.	Northome, WWTP Northome (Koochiching)	M/2	1977/6	0.044 (design)	NA	Marsh head water Cattail-shrubs	PEM2A	Marsh area in head waters of creek	NA

Table 4.2-1

MINNESOTA (concluded)

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
25.	Perham WWTP Perham (Otter Tail)	M+I	1936/43	0.400	16	Cattail-willow slough	PEM1G PSS1	CW, S, SR discharges	High
26.	Ramey Farmers Coop Creamery Ramey (Morrison)	I	1913/5+	0.191	25	Wet meadow Reed canary grass marsh	PEM2D	Wild., game birds CW, PW discharges go to man-made ditch that enters wetland	Low
27.	Reynolds Coop Creamery Long Prairie (Todd)	I	-/30	0.012	5-6	Lagoon area	NA	Man-made lagoon 4 feet deep is used by ducks PW, CW discharges	Low
28.	Rose Coop Creamery Eagle Bend (Todd)	I	NA	0.0035	NA	Marsh	NA	Marshy area surrounding Stormy Creek PW and S (overflow) discharges	Low
29.	St. Joseph WWTP St. Joseph (Stearns)	M/2	1961/19	0.240	15	Cattail marsh Tamarack-sphagnum bog	L1AB1A PEM1 PFO2a	Rec., Wild., Duck Cl_2 discharge	High
30.	Shafer WWTP Center City (Chisago)	M/3	1967/13	0.020	240	Tamarack-sphagnum bog	PEM1D PFO2a	Rec., Wild, Duck; borders trout stream 10-acre marsh 200-acre bog Spring/Fall discharge to be cont'd	High
31.	Staples WWTP Staples (Todd)	M/2	1963/25	0.325	200-300	Cattail marsh	PEM1Bb	Wild. Cl_2 discharge, odor problems	High
32.	Sunburg Coop Creamery Sunburg (Kandiyohi)	I	NA	0.003	NA	Landlocked pond Marsh	PAB1B PEM	Rec. Excessive phytoplankton PW, CW, S discharges	Moderate
33.	Taconite WWTP Taconite (Itasca)	M/1	-/70	0.050	1	Lake surrounded by marsh	NA	Formerly an open pit mine Discharge scheduled to stop by 1985	Low
34.	Upsala WWTP Upsala (Morrison)	M/2	1964/-	0.036	NA	Swamp	NA	NA	NA
35.	Wahkon WWTP Wahkon (Mille Lacs)	M/2	1977/3	0.014	200	Cattail-willow marsh	PEM1D PSS1	Rec., Wild., Duck	Low
36.	Winton WWTP Winton (St. Louis)	M/3	1961/19	0.023	NA	Herbaceous marsh	PEM2	Discharge flows through marsh for 100 yards before reaching Fall Lake	Low

Table 4.2-1

OHIO

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
1.	Gambier WWTP Gambier (Knox)	M	1938+67/42	0.186	200	Oxbow slough Bottomland hardwood forest	PFO1Ac	Discharge from oxbow to Walhonding River	High
2.	Hinde Subdivision STP Sandusky (Erie)	M/2	1957/23	0.160	NA	Shallow, narrow pond	PM1D PFO5	Fish, Rec., city water supply Scheduled to be abandoned Pond called "Kob Ditch"	Low
3.	Uniroyal, Inc. Erie Industrial Park Port Clinton (Ottawa)	I/2	NA	0.447	NA	Marsh	NA	PW, S discharges 7 industries present in Park Marsh area is an old weapons testing area; completely off limits	None

Table 4.2-1

WISCONSIN

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
1.	Amani Sanitary District Amery (Polk)	M/2	NA	0.006	NA	Wooded swamp	PFO3	Ditch to wetland to Horse Creek Surrounded by a hardwood forest	NA
2.	Arcadia WWTP Arcadia (Trempealeau)	M/2	NA	0.010	3 (pond-marsh) 1,000 forest	Marsh Bottomland forest	PEM1D PSS PFO3E	Wild. Pond surrounded by marsh drains into forest; potential to study recovery	Moderate
3.	Associated Milk Producers, Inc. (AMPI) Turtle Lake (Barron)	I/2	NA	NA	10-20	Cattail-tag alder marsh	PEM1A PSS1A	Wild. Public hearing commenced with Village of Turtle Lake for determination of wetland classification by WDNR	High
4.	Brillion STP Brillion (Calumet)	M+I	-/50	0.300	600	Cattail marsh	PEM1A	Part of marsh has burned New plant scheduled to be constructed - 1980 Duck, Rec., Wild. Spring water back-ups occur	Low
5.	Chili Sanitary District Chili (Clark)	M/2	1968/13	0.037	3	Cattail marsh Shrub swamp Wooded swamp	PEM1 PSS1 PFO3	Lagoons discharge twice annually (total 5 mg per year)	Moderate
6.	Curtiss WWTP Curtiss (Clark)	M	1977/3	0.007	20-30	Tag alder swamp	PSS1D	Duck, Rec. Only flooded during part of year	Moderate
7.	Dresser WWTP Dresser (Polk)	M/2	NA	0.102 (design)	NA	Cattail marsh	PEM1Bc	NA	NA
8.	Drummond Sanitary District #1 Drummond (Bayfield)	M/2	1979/2	0.100	8	Bog	PML PFO4	Rec., Wild. *Elodea* problem	High
9.	Elk Mound Water and Sewer Utility Elk Mound (Dunn)	M	1969/11	0.045 (design)	1-2	Cattail-tag alder swamp	PEM1c PSS1	Drainage area tributary to Muddy Creek One mg polishing pond prior to wetland;discharge to be moved out of wetland in 1983	Low
10.	Florence Municipal Sewer System Florence (Florence)	M/2	NA	0.086	NA	Seasonally flooded basin or flat	NA	Discharge from wetland to a Class I trout stream (Weber Creek)	Low

Table 4.2-1

WISCONSIN (continued)

	Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
11.	Gilson Brothers Co. Plymouth (Sheboygan)	I	1966/-	0.029	5-10	Reed canary grass marsh Tag alder swamp	PEM2 PSS1	Duck, Wild. PW, CW, S, Cl_2 discharges Stream channel flows through swamp and marsh	High
12.	Hillshire Farms Co. New London (Outagamie)	I/3	1974/6	1.000	11	Cattail marsh	PEM1A	Marsh used as polishing pond Cl_2 discharge goes through man-made ditch to marsh	High
13.	Kasson Cheese Co. Brillion (Calumet)	I	NA	0.028	NA	Bottomland forest swamp	PEM1 PFO3	Wild., Duck Plant scheduled for new construction CW, PW discharges	Low
14.	Lakeside Cheese Factory (Henning's Cheddar Cheese) Kiel (Manitowoc)	I/2	NA	0.007	NA	Shrub marsh	PSS	CW, WW discharges	Low
15.	Menasha Corp. Neenah Container Div. Neenah (Winnebago)	M/2	1971/16	0.015	20	Cattail-shrub slough	PAB2A PEM1 PSS PFO3	Rec., Duck, Wild., Crop Discharge to man-made ditch, then to Neenah Slough Slough is several miles long S, SR, Cl_2 discharges	High
16.	Milltown WWTP Milltown (Polk)	M	NA	0.090 (design)	5-10	Cattail marsh	PEM1D	Discharge not found during site visit	Low
17.	Muskego NE District STP Muskego (Waukesha)	M	NA	0.933	NA	Marsh borders a lake	NA	Rec., Wild. Discharge ditch for 0.1 mile through wetand to Muskego Lake High BOD, SS, P	Low
18.	New Auburn WWTP New Auburn (Chippewa and Barron)	M	NA	NA	NA	Cattail marsh	PEM1	Duncan Creek (trout stream) headwaters in marsh	NA
19.	Northernaire Lake Terrace Three Lakes (Oneida)	M	1965/-	NA	100	Spruce bog Wooded swamp	PFO3	Discharge flows underground through bog for 0.5 mile to Little Moccasin Lake	Moderate
20.	Oconomowoc Electroplating Co. Ashippun (Dodge)	I	1966/14	0.100	20	Seasonally flooded basin or flat	NA	Discharge to Davey Creek, a tributary of Rock River	Low

Table 4.2-1

WISCONSIN (continued)

Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
21. Ogema Sanitary District #1 Ogema (Price)	M/2	NA	0.050 (design)	NA	Wooded swamp	PFO	Swamp bounded by roads on all sides	NA
22. Paddock Lake WWTP Paddock Lake Wisconsin (Kenosha)	H/2	1957/26	0.262	150	Marsh; shrub border	PEMA	Designated significant natural area	High
23. Pence WWTP Pence (Iron)	M/1	~/30	NA	20	Marsh Wooded swamp	PEM PFO	Culvert through marsh	NA
24. Phelps Sanitary District #1 Phelps (Vilas)	M/2	1972/8	0.680	30	Wooded swamp	PSS1A PFO3,4	Rec., Duck, Wild. High asbestos fiber counts	High
25. Radisson STP Radisson (Sawyer)	M/2	1968/12	0.001	5	Marsh Shrub-wooded border	PEM1G PSS1 PFO3,4	Rec., Wild. New construction will stop discharge	Moderate
26. Rockland Sanitary District #1 Rockland (La Crosse)	M/2	1967/13	0.020	20	Herbaceous, shrub, wooded swamp	PAB3D PEM2 PSS1 PFO1	Fish, Rec., Wild. Cl_2 discharge	High
27. Seeger's Dairy Merrill (Lincoln)	I/1	1950/30	0.0003	5	Bog Swamp	PEMD PFO	Duck, Rec. CW, WW discharges	Moderate
28. Shawano County Health Care Facility Shawano (Shawano)	O/2	NA	0.012-0.015	NA	Reed canary grass marsh Ash-elm swamp	PEM2 PFO1	Duck, Wild. Dikes around lagoons, leak due to muskrats	Moderate
29. Sherwood STP Sherwood (Calumet)	M	1977/3	4.0-5.0	7 mi. (creek bed)	Cattail marsh	PEM1	Discharges to stream, then to marsh on fill and draw basis (twice a year for 5 days)	NA
30. Siren WWTP Siren (Burnett)	M/2	NA	NA	NA	Cattail marsh Bog	PEM1 PFO4	Seepage to bog may occur Discharge is to marsh	Moderate
31. Stockbridge Sanitary District Stockbridge (Calumet)	M/2	1960/20	NA	5	Cattail marsh	PEM1D	Wild. Discharge is overflow from lagoon to Mud Creek (a narrow floodplain)	Moderate
32. Three Lakes Sanitary District #1 Three Lakes (Oneida)	M/2	-/30	0.050	20	Herbaceous-shrub marsh Forested swamp	PAB3D PEM PSS PFO1	Crop, Wild., Rec. Thunder Lakes Marsh and Townline Lake may receive discharge	High
33. Tony STP Tony (Rusk)	M/2	1974/3.5	0.002	NA	Tamarack swamp	PSSA PFO2	Wild., Rec. Discharge flows from ditch to wetland to ditch to Deertail Creek	Low

Table 4.2-1

WISCONSIN (concluded)

Name Location (County)	Type of Facility/ Treatment	Operational Date/No. of Years of Discharge	Quantity of Discharge (MGD)	Acreage of Wetland	General Description of Wetland	FWS Classification	Significant Aspects/ Comments	Potential as Study Site
34. Turtle Lake Sewer and Water Department Turtle Lake (Barron)	M+I/2	NA	0.075	10-20	Cattail-tag alder marsh	PEM1A PSS1A	As of July 1980, hearing request in conjunction with AMPI Odor problems Overloaded system	High
35. Whitehall WWTP Whitehall (Trempealeau)	M+I/3	-/5	0.050	60	Shrub-wooded swamp	PEM2D PSS1 PFO1	Wild., Duck, Rec. Irregular dischage to man-made ditch that enters wetland	High
36. Whitewater Municipal Water Utility Well #6 Whitewater (Walworth)	M	1965/15	0.120/ week	40	Herbaceous, shrub, wooded marsh	PEM1 PSS1 PFO1	Crop, Wild. Discharge is backwash from Fe removal filters	Moderate
37. WDNR-Peninsula State Park Fish Creek (Door)	M/2	-/15	NA	15	Herbaceous marsh	PEM1A PSS	Duck Bog mat vegetation Third lagoon is located in marsh Discharge on fill and draw basis (only in spring)	Low

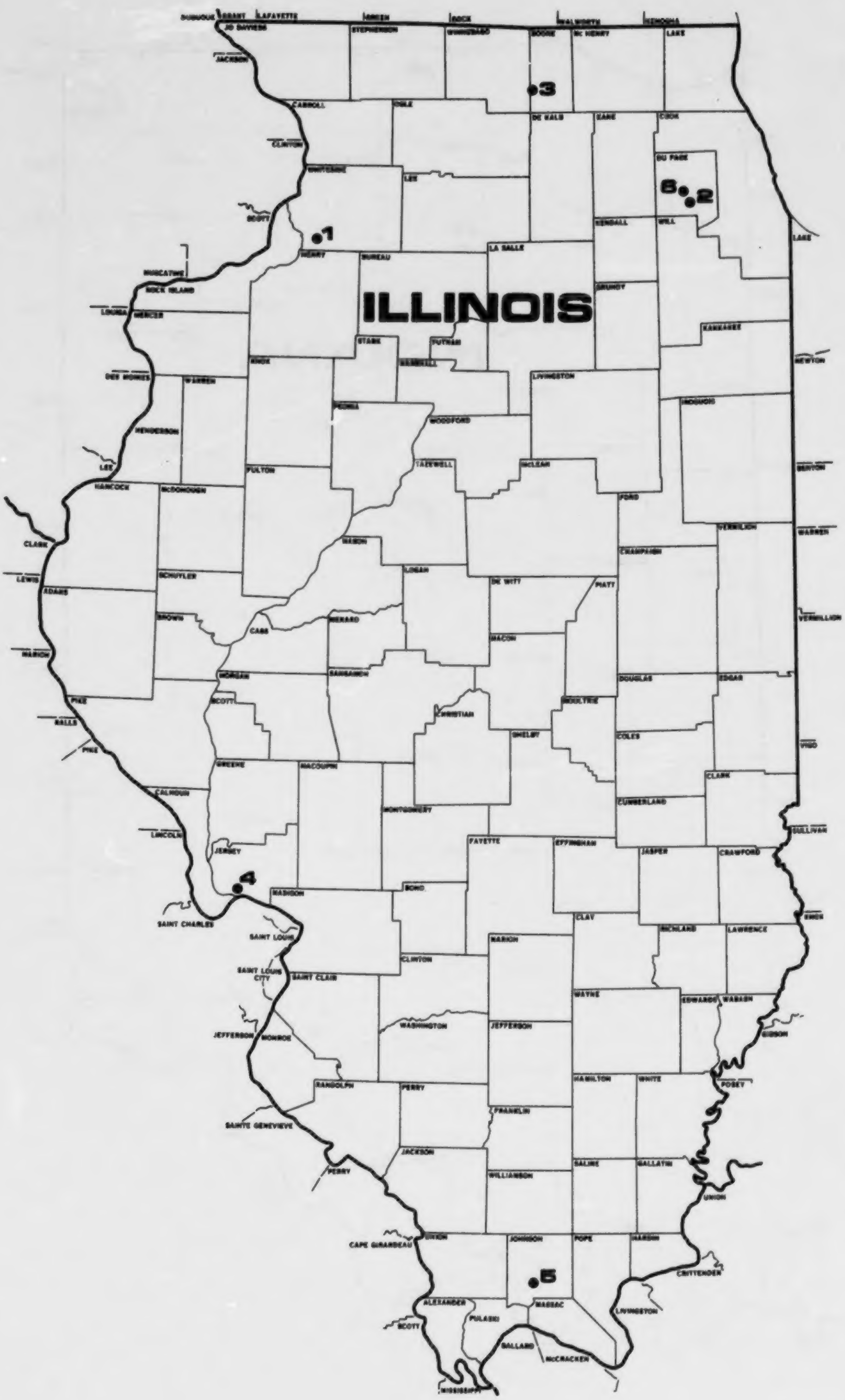

ILLINOIS
1
2
3
4
5
6
JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
COOK
DU PAGE
WHITESIDE
LEE
KENDALL
WILL
HENRY
BUREAU
LA SALLE
GRUNDY
KANKAKEE
ROCK ISLAND
MERCER
STARK
PUTNAM
MARSHALL
KNOX
WARREN
HENDERSON
PEORIA
WOODFORD
LIVINGSTON
IROQUOIS
HANCOCK
MCDONOUGH
FULTON
TAZEWELL
MCLEAN
FORD
VERMILION
MASON
CHAMPAIGN
ADAMS
SCHUYLER
BROWN
CASS
MENARD
LOGAN
DE WITT
PIATT
MACON
MORGAN
SCOTT
SANGAMON
CHRISTIAN
MOULTRIE
DOUGLAS
EDGAR
PIKE
SHELBY
COLES
CLARK
GREENE
MACOUPIN
CALHOUN
MONTGOMERY
CUMBERLAND
JERSEY
FAYETTE
EFFINGHAM
JASPER
CRAWFORD
MADISON
BOND
CLAY
RICHLAND
LAWRENCE
MARION
CLINTON
SAINT CLAIR
WAYNE
EDWARDS
WABASH
WASHINGTON
JEFFERSON
MONROE
RANDOLPH
PERRY
HAMILTON
WHITE
FRANKLIN
JACKSON
WILLIAMSON
SALINE
GALLATIN
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC

Figure 4.2-1. Facilities identified as discharging to a wetland in Illinois.

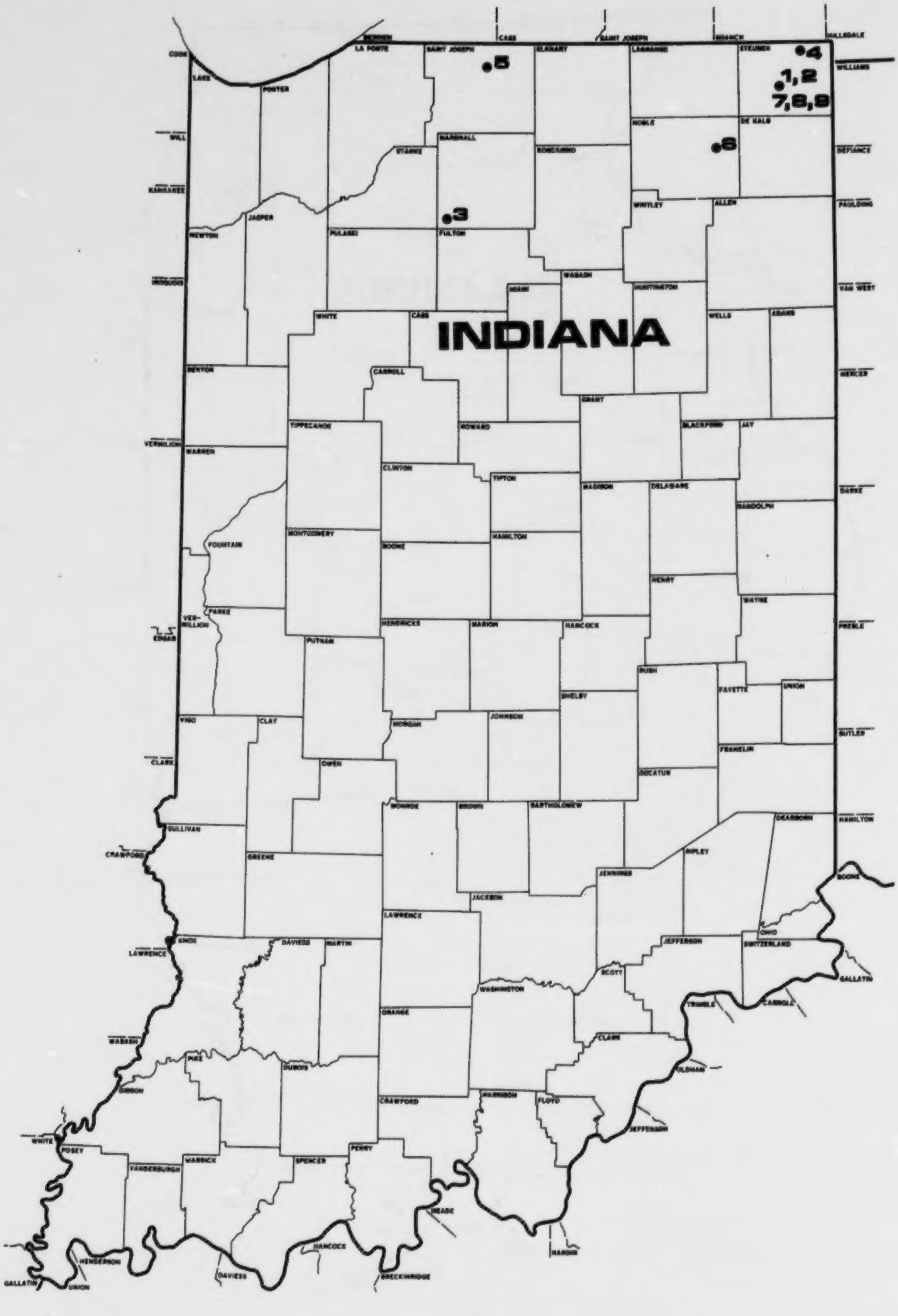
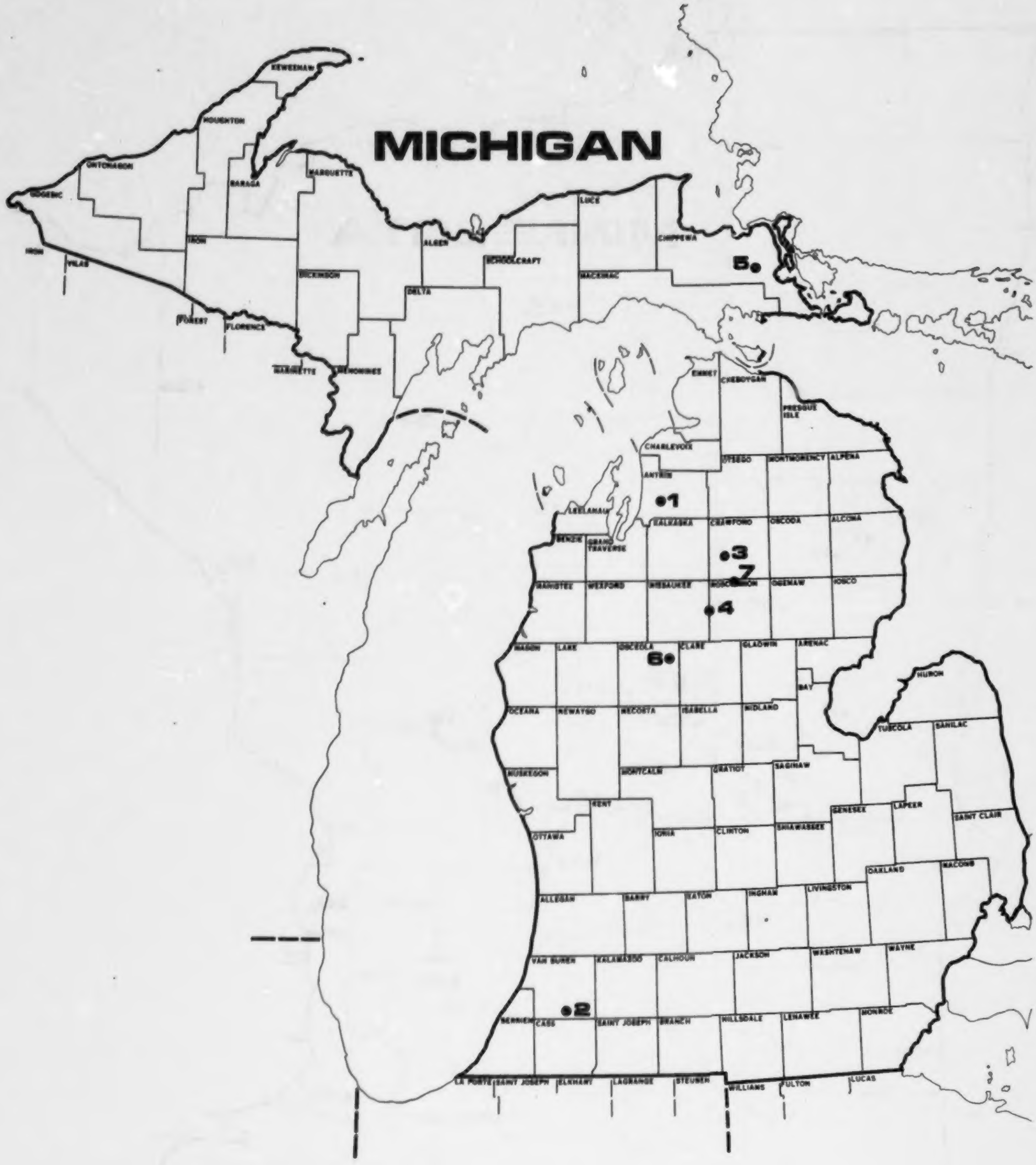

INDIANA
5
4
1,2
7,8,9
6
3

Figure 4.2-2. Facilities identified as discharging to a wetland in Indiana.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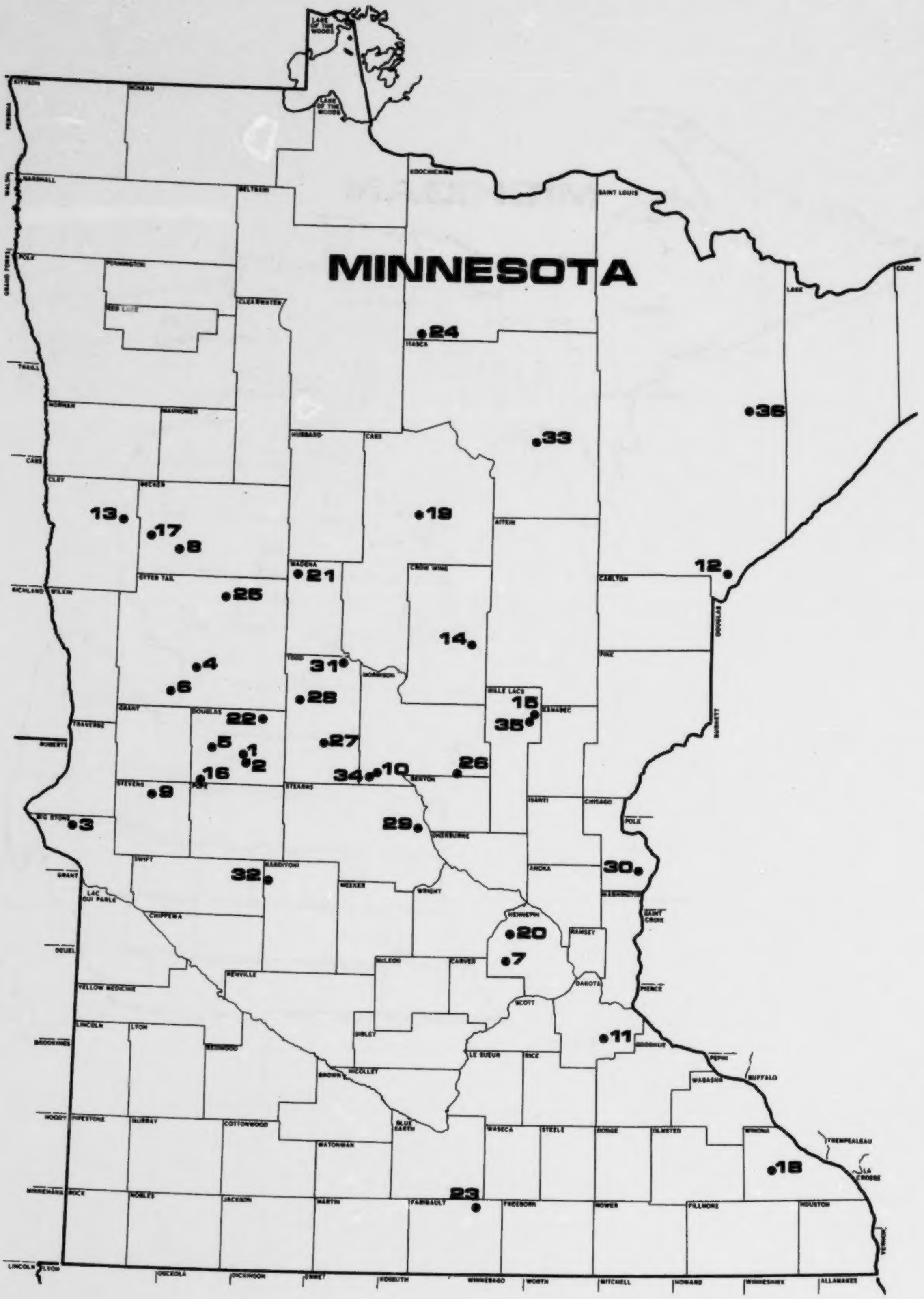
KEWEENAW
HOUGHTON
ONTONAGON
GOGEBIC
BARAGA
MARQUETTE
IRON
VILAS
ALGER
LUCE
CHIPPEWA
SCHOOLCRAFT
MACKINAC
DICKINSON
DELTA
FOREST
FLORENCE
MARINETTE
MENOMINEE
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
ANTRIM
OTSEGO
MONTMORENCY
ALPENA
LEELANAU
KALKASKA
CRAWFORD
OSCODA
ALCONA
BENZIE
GRAND TRAVERSE
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
BAY
HURON
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
KENT
OTTAWA
IONIA
CLINTON
SHIAWASSEE
GENESEE
LAPEER
SAINT CLAIR
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
MACOMB
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
SAINT JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE
LA PORTE
SAINT JOSEPH
ELKHART
LAGRANGE
STEUBEN
WILLIAMS
FULTON
LUCAS
1
2
3
4
5
6
7

Figure 4.2-3. Facilities identified as discharging to a wetland in Michigan.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LAKE OF THE WOODS
KITTSON
ROSEAU
KOOCHICHING
MARSHALL
BELTRAMI
SAINT LOUIS
POLK
PENNINGTON
RED LAKE
CLEARWATER
COOK
LAKE
ITASCA
NORMAN
MAHNOMEN
HUBBARD
CASS
CLAY
BECKER
AITKIN
WADENA
CROW WING
CARLTON
OTTER TAIL
WILKIN
TODD
MORRISON
PINE
MILLE LACS
KANABEC
GRANT
DOUGLAS
TRAVERSE
STEVENS
POPE
STEARNS
BENTON
ISANTI
CHISAGO
BIG STONE
SWIFT
KANDIYOHI
MEEKER
WRIGHT
SHERBURNE
ANOKA
WASHINGTON
LAC QUI PARLE
CHIPPEWA
HENNEPIN
RAMSEY
RENVILLE
MCLEOD
CARVER
DAKOTA
SCOTT
YELLOW MEDICINE
LINCOLN
LYON
REDWOOD
SIBLEY
LE SUEUR
RICE
GOODHUE
BROWN
NICOLLET
WABASHA
PIPESTONE
MURRAY
COTTONWOOD
WATONWAN
BLUE EARTH
WASECA
STEELE
DODGE
OLMSTED
WINONA
ROCK
NOBLES
JACKSON
MARTIN
FARIBAULT
FREEBORN
MOWER
FILLMORE
HOUSTON
PEMBINA
WALSH
GRAND FORKS
TRAILL
CASS
RICHLAND
ROBERTS
GRANT
DEUEL
BROOKINGS
MOODY
MINNEHAHA
LINCOLN
LYON
OSCEOLA
DICKINSON
EMMET
KOSSUTH
WINNEBAGO
WORTH
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
VERNON
LA CROSSE
TREMPEALEAU
BUFFALO
PEPIN
PIERCE
SAINT CROIX
POLK
BURNETT
DOUGLAS
24
36
33
19
13
17
8
21
12
25
14
4
31
6
28
15
35
22
5
1
27
2
16
34
10
26
9
3
29
32
30
20
7
11
18
23

Figure 4.2-4. Facilities identified as discharging to a wetland in Minnesota.

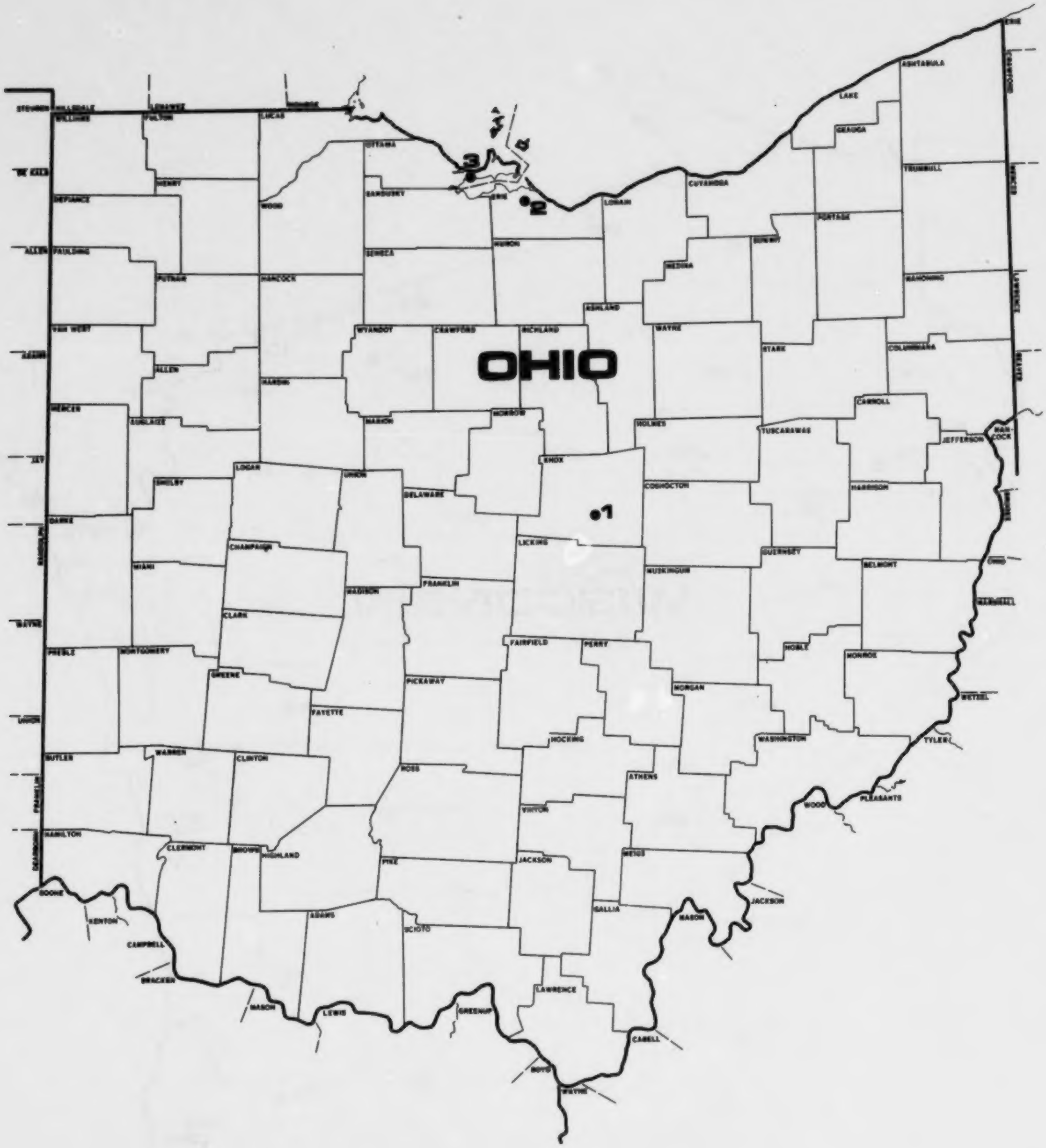
OHIO
1
2
3
WILLIAMS
FULTON
LUCAS
OTTAWA
ERIE
LORAIN
CUYAHOGA
LAKE
ASHTABULA
GEAUGA
TRUMBULL
DEFIANCE
HENRY
WOOD
SANDUSKY
HURON
MEDINA
SUMMIT
PORTAGE
PAULDING
PUTNAM
HANCOCK
SENECA
ASHLAND
WAYNE
STARK
MAHONING
VAN WERT
ALLEN
HARDIN
WYANDOT
CRAWFORD
RICHLAND
COLUMBIANA
MERCER
AUGLAIZE
MARION
MORROW
HOLMES
TUSCARAWAS
CARROLL
JEFFERSON
SHELBY
LOGAN
UNION
DELAWARE
KNOX
COSHOCTON
HARRISON
DARKE
CHAMPAIGN
LICKING
GUERNSEY
BELMONT
MIAMI
MADISON
FRANKLIN
MUSKINGUM
CLARK
PREBLE
MONTGOMERY
GREENE
FAIRFIELD
PERRY
NOBLE
MONROE
FAYETTE
PICKAWAY
MORGAN
BUTLER
WARREN
CLINTON
HOCKING
WASHINGTON
ROSS
ATHENS
HAMILTON
CLERMONT
BROWN
HIGHLAND
VINTON
MEIGS
PIKE
JACKSON
GALLIA
ADAMS
SCIOTO
LAWRENCE

Figure 4.2-5. Facilities identified as discharging to a wetland in Ohio.

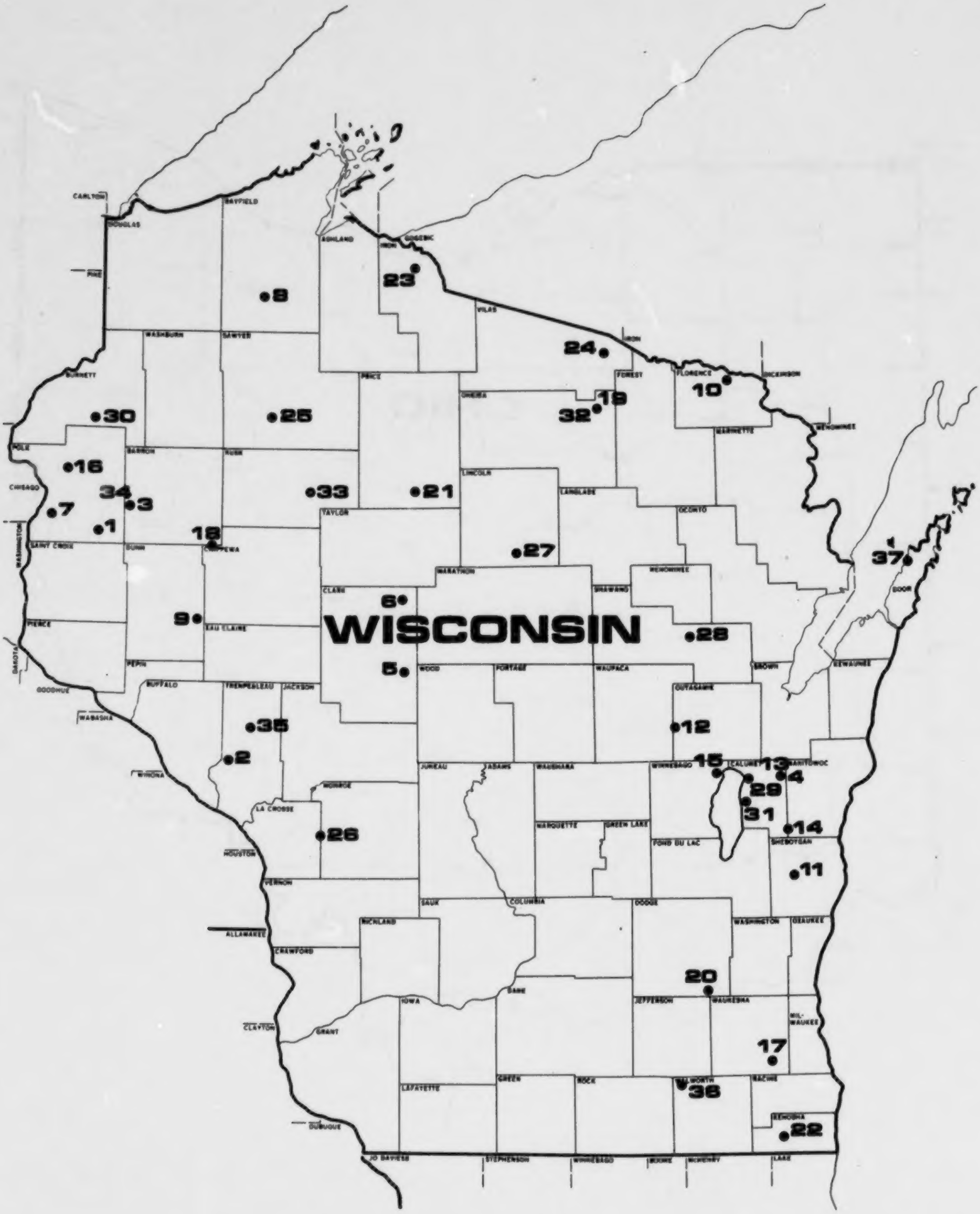
WISCONSIN
CARLTON
DOUGLAS
BAYFIELD
ASHLAND
IRON
GOGEBIC
PINE
VILAS
8
23
WASHBURN
SAWYER
IRON
24
BURNETT
PRICE
FOREST
FLORENCE
DICKINSON
10
ONEIDA
19
32
30
25
MARINETTE
MENOMINEE
POLK
BARRON
RUSK
16
CHISAGO
34
3
33
21
LINCOLN
LANGLADE
7
1
TAYLOR
OCONTO
18
CHIPPEWA
WASHINGTON
SAINT CROIX
DUNN
27
37
MARATHON
MENOMINEE
DOOR
CLARK
SHAWANO
6
PIERCE
9
EAU CLAIRE
28
DAKOTA
PEPIN
5
WOOD
PORTAGE
WAUPACA
BROWN
KEWAUNEE
GOODHUE
BUFFALO
TREMPEALEAU
JACKSON
OUTAGAMIE
WABASHA
35
12
2
JUNEAU
ADAMS
WAUSHARA
WINNEBAGO
15
CALUMET
13
MANITOWOC
4
WINONA
MONROE
29
31
LA CROSSE
MARQUETTE
GREEN LAKE
14
26
FOND DU LAC
SHEBOYGAN
HOUSTON
11
VERNON
SAUK
COLUMBIA
DODGE
ALLAMAKEE
RICHLAND
WASHINGTON
OZAUKEE
CRAWFORD
20
DANE
IOWA
JEFFERSON
WAUKESHA
MIL-WAUKEE
CLAYTON
GRANT
17
LAFAYETTE
GREEN
ROCK
WALWORTH
RACINE
36
KENOSHA
22
DUBUQUE
JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
MCHENRY
LAKE

Figure 4.2-6. Facilities identified as discharging to a wetland in Wisconsin.

Table 4.2-2. Summary of known wetland discharge sites in USEPA Region V by type of facility. Data are current as of November 1980.

	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin	Region V	Percent of Total
Municipal[a]	4	4	7	28	2	29	74	76
Industrial[b]	1	-	-	5	1	7	16	17
Commercial	-	-	-	2	-	-	2	2
Other[c]	1	3	-	1	-	1	6	6
Total	6	9	7	36	3	37	98	100
Approximate Percent of Region	6	9	7	36	3	39	100	

---

[a] Municipal facilities include water treatment plants.

[b] Industrial facilities include creameries.

[c] Other facilities include parks, mobile home communities, shopping centers, and semi-public facilities such as truck stops.

Site accessibility was determined for those facilities visited during the field investigations, as described in Section 4.1.3. Those facilities not visited were categorized in this regard only in cases where information on their accessibility was included in files or reports. Similarly, the potential for sampling at each site was assessed for facilities actually visited. Both accessibility and potential for sampling were assumed to be high if previous or current research were known to be conducted on a site.

4.2.1.1 Classification of Wetlands

Each wetland identified as a wastewater discharge site was classified according to the scheme developed by the US Fish and Wildlife Service for the National Wetland Inventory (Cowardin et al. 1979). A tentative identification was made of the type(s) of wetland(s) that were present at each of these sites, based on the information obtained from agency files and from returned questionnaires. The classifications for the sites not visted during the initial field investigations must be considered as approximations only. A comparison of the general terms for vegetated inland wetlands used in Wisconsin with the terms used in the new USFWS wetland classification scheme is presented in Table 4.2-3.

It was extremely difficult to identify water regime modifers for each site from the information on the survey forms. This information also is to be considered merely an approximation until confirmed through field inspections. In addition, many of the sites have received treated wastewater for at least several years, and the present structural characteristics and species composition of these areas may not be indicative of the conditions of the wetlands prior to initiation of the discharges.

Based on the estimated classification of each wetland by the USFWS system (Column 6 of Table 4.1-1), the number of wetlands of each type that presently receive treated wastewater was estimated for each state (Table 4.2-4). Wetlands were grouped into 8 categories on the basis of the combinations of types of vegetation present. For 14 of the facilities that discharge to wetlands (15% of the total), the information available was insufficient to classify according to the USFWS system. These facilities have been listed in a sepa-

Table 4.2-3. Comparison of general terms for wetlands used in Wisconsin with terms used in the US Fish and Wildlife Service Wetland Classification System (after Novitzki 1979). Wetland plant communities are listed in sequence from wettest to driest sites.

Local terms used in Wisconsin (Bedford et al. 1974)	Equivalent terms used in USFWS System[a] (Cowardin et al. 1979)
Pond, marsh, sedge meadow, fen, bog	Emergent wetland
Shrub swamp, shrub fen, shrub bog, forest bog	Scrub/shrub wetland
Floodplain forest, wooded swamp, cedar swamp, forested fen	Forested wetland

---

[a] Terms used are classes in this system - descriptors that indicate the general appearance of the habitat in terms of the dominant life form of the vegetation.

Table 4.2-4. Summary of wetland discharge sites in USEPA Region V by type of wetland. The key to the symbols used in the FWS classification system is given on the first page of Table 4.2-1. Data are current as of November 1980.

	1	2	3	4	5	6	7	8	9	10	11
STATE	PAB PEM	PAB PEM PSS	PAB PEM PSS PFO	PML PEM PSS PFO	LAB LRS LSS	PAB PSS PFO	PFO	RFO	RAB PEM	NA	TOTAL
Illinois	3	1	0	0	0	1	0	0	0	1	6
Indiana	2	3	2	0	1	0	1	0	0	0	9
Michigan	1	1	1	1	1	0	0	2	0	0	7
Minnesota	14	7	1	1	2	0	1	0	1	9	35
Ohio	0	0	1	0	0	0	1	0	0	1	3
Wisconsin	7	6	13	1	0	4	3	0	0	3	36
TOTAL	27	18	18	3	4	5	6	2	1	14	98
PERCENT OF TOTAL	28	18	18	3	4	5	6	2	1	15	100

---

[1] Emergent vegetation present with or without open water (PAB, PEM, or PAB/PEM).

[2] Emergent and shrub vegetation present with or without open water (PAB/PEM/PSS, or PEM/PSS).

[3] Emergent, shrub, and/or forest vegetation present with or without open water (PEM/PFO, PEM/PSS/PFO, or PAB/PEM/PSS/PFO).

[4] Moss/lichen vegetation present in combination with emergent, shrub, and/or forest vegetation (PML/PFO, PML/PEM/PSS, or PML/PEM/PSS/PFO).

[5] A significant open-water area present (Lacustrine System). A combination of aquatic, emergent, shrub, and/or forest vegetation surrounded the water body (LSS, LAB/PEM/PFO, or LRS/PEM).

[6] Shrub and forest vegetation present with or without open water (PAB/PSS/PFO, PSS, or PSS/PFO).

[7] Forest vegetation present in the Palustrine System (PFO)

[8] Forest vegetation present in the Riverine System (RFO)

[9] Riverine aquatic vegetation present with emergent vegetation adjacent to it (RAB/PEM)

NA - Insufficient information available to classify wetlands.

rate column and given the designation NA (information not available) (Table 4.2-4). The greatest number of discharges to wetlands in Region V are to palustrine emergent wetlands associated with river floodplains or streams. These wetlands are primarily cattail marshes. The numbers in Table 4.2-4 are estimates made on the basis of limited information, and are presented solely to provide an overview.

4.2.1.2 Geographic Distribution of Sites

Figures 4.2-1 through 4.2-6 illustrate the geographical distribution of the 161 sites. The majority identified (37%) were in Wisconsin, and 73 of the sites (75%) occur in Minnesota and Wisconsin.

4.2.2 Existing, Planned, and Potential Wetland Treatment Sites

At present, three systems designed for the treatment (not merely the discharge) of secondarily treated wastewater by natural wetlands are operational in EPA Region V. These include two in Michigan and one in Wisconsin (Table 4.2-5). During the the inventory, sites were identified at which discharges to wetlands may be initiated or terminated between 1981 and 1983. Several of these sites, also listed in Table 4.2-5, may be designed as wetland treatment systems. It is probable that a number of facilities presently in operation, under construction, or in various steps of the construction grants process in USEPA Region V may have wetland discharges during the period 1981-1985.

No wetlands constructed specifically for the treatment of wastewater from a municipality or industrial facility currently are in operation in Region V. One research facility is operating at present on the campus of Michigan State University in East Lansing, Michigan, and a small pilot facility was operated at Seymour, Wisconsin, during 1975 by researchers from the University of Wisconsin at Oshkosh (Spangler et al. 1976). Descriptions of the studies at both of these sites will be given in a publication being prepared by Hammer and Kadlec. A constructed wetland has been designed as part of a new treatment facility to be constructed at Bement, Illinois, but the project has since been abandoned due to a state requirement for limiting the levels of ammonia to 1.5 mg/l, which was

Table 4.2-5. Existing, planned, and potential wetland treatment sites in USEPA Region V.

Treatment Site	Type of Treatment/ No. Years of Discharge[1]	Comments
I. Natural Wetlands		
A. Existing[2]		
1. Bellaire WWTP Bellaire MI	2°/10	Four-point pipeline Wet meadow/swamp
2. Drummond Sanitary District Drummond WI	2°/2	Multiple-point pipeline Bog
3. Houghton Lake WWTP Houghton Lake MI	2°/3	Multiple-point pipeline Wet meadow
B. Proposed/Potential[3]		
1. Biwabik WWTP Biwabik MN	--	Proposed discharge to an acid bog for 7 months/year Construction may be completed during 1982 or 1983
2. Kilkenny WWTP Kilkenny MN	--	Discharge would be to culvert that passes through an unnamed marsh
3. Laona Sanitary District Laona WI	--	Presently discharges to Rat River - discharge will be rerouted to wetland on US Forest Service property

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[1] Secondary treatment indicated by 2°.

[2] Designed as a wetland treatment system.

[3] Some wetland sites designated only as discharge points; potential exists for design of wetland treatment system.

[4] Operational systems that treat all of the wastewater discharged by a municipality or industrial facility.

determined not attainable with these systems. The constructed system was also determined not to be cost-effective in this particular case.

4.2.3 Volunteer Wetlands

A special class of wetlands exists because of the direct or indirect results of the design, construction, and operation of wastewater treatment facilities. Irrigation fields or storage lagoons that receive secondarily treated wastewater may become wetland ecosystems under certain circumstances. Based on information obtained during the inventory of discharges for this study and on personal communications with state agency personnel and university researchers, it appears that such "volunteer" wetlands are much more common in USEPA Region V than has been previously suspected. Volunteer wetlands typically include large stands of cattails, and are either periodically or permanently inundated. They are typified by high water levels due to artificial dikes or berms. Access to such sites is likely to be prohibited by the normal isolation, distances, and fencing required at waste treatment facilities. These wetlands commonly are located close to treatment lagoons or treatment plants. Flow patterns often are well-defined, and discharges are under the control of the plant operator.

Discharges to volunteer wetlands have occurred for varying periods of time at different locations, and none are known to have been studied in detail. The plant communities in such wetlands that have been observed for a period of years have been reported to develop into cattail monocultures, as is the case at Vermontville, Michigan (Bevis 1979; Sutherland and Bevis 1979). This site was determined to treat wastewater effectively in a cost-competitive manner. No construction was required except for the ponds, and no maintenance (such as removal of vegetation) was performed (although this may be determined to be necessary at some point, such as for removal of a buildup of cattail straw).

As indicated in Section 4.2.1, volunteer wetland vegetation at three land application sites in Michigan (Table 4.2-6) has developed to the degree that the sites are assuming the appearance and certain functions of naturally-occurring wetlands, and the quality of the wastewater passing through each of

Table 4.2-6. Volunteer wetlands known to exist in USEPA Region V.

Location of Site	Part of Facility/Site Where Wetland Vegetation Has Developed
1. Lake Odessa and Leona Township Lake Odessa MI	Spray irrigation fields
2. Paw Paw WWTP Paw Paw MI	Flood irrigation fields
3. Vermontville WWTP Vermontville MI	Flood irrigation fields

these areas is being improved. Based on conversations with various researchers and the tendency for wetland plants to colonize stabilization ponds and areas adjacent to wastewater treatment facilities, many such "unintentional" artificial wetlands are probably present in Region V.

5.0. ISSUE PRIORITIES AND ASSIGNMENT OF STUDY TOPICS

5.1 Introduction

Ideally, all of the major issues concerning the effects of wastewater on wetlands identified during the present study should be included in the Phase II program. However, completion of detailed sampling programs at each of the 26 sites designated as having a high potential for further research is not possible due to cost and manpower limitations. Furthermore, to investigate of all of the major issue categories at even a single site would also be cost-prohibitive. In view of these limitations and the need to optimize the types, amounts, and usefulness of the information gathered in Phase II, U.S. EPA determined that the issues first needed to be ranked with respect to their overall significance. Such a ranking procedure will ultimately provide a means of selecting specific issues to be examined in Phase II as well as establishing funding priorities for the field sampling program at individual sites. EPA also determined that generalized study topics needed to be assigned to each major category as a first step in designing the field sampling program for Phase II. This approach will contribute to the fine tuning of eventual site-specific selection criteria for Phase II, in which an actual sampling program will be designed for each wetland.

Following review of the initial draft Phase I report by the Technical Advisory Committee, and incorporation of major technical comments, EPA determined a suitable ranking scheme for the major issues, and assigned major study topics to each issue category.

Based on an extensive internal discussion and a thorough literature review of the known effects of wastewater on wetlands, a set of six major issue categories were selected. These were then ranked relative to each other based on their overall significance. The issue categories, ranked in decreasing priority, are as follows:

- Use of constructed wetlands;
- Impact on hydrologic regime;
- Long-term biological effects;
- Legal/regulatory administrative issues;
- Mitigation/management issues; and
- Disease/health considerations.

The following paragraphs summarize the rationale for selecting and ranking each of the major issue categories, why they are important, and what the study of these issues will contribute to the Generic EIS.

5.1.1 Use of Constructed Wetlands

Constructed wetlands were assigned top priority for several reasons. Recent studies have clearly shown that constructed wetlands provide a highly effective means of achieving either secondary treatment standards on a year-round basis or advanced treatment standards on a seasonal basis (Wile et al. 1983). These systems can also be designed to allow control over the underlying substrate (through liners, trough systems, or choice of placement). This means that loading rates and subsurface losses to groundwater, which may or may not occur in a natural wetland are completely controllable in a constructed wetland. In addition, the type of soil and vegetation can be selected at will to optimize treatment effectiveness. Constructed wetlands are also versatile in that they may be used either as a means of final "polishing" or as the primary means of secondary treatment. The systems developed to date have also been shown to be cost competitive with more standard techniques. Finally, the use of constructed wetlands for wastewater treatment does not impact existing natural wetlands. Therefore the constructed wetland alternative is less controversial and may not involve an extensive regulatory review process as is the case with discharges to natural systems. As a cost-effective alternative with few regulatory difficulties, therefore, constructed wetlands should be ranked very highly for additional consideration and funding for further study. No full scale constructed wetland currently exists in U.S. EPA Region V, however research has been conducted in areas with comparable climatologic constraints. All of these factors led to the assignment of a top priority to the further consideration of the constructed wetland alternative. Additional study of this alternative will be a highly valuable contribution to the draft Generic EIS.

Specific subjects for further study in Phase II would include: (1) selection of a possible new full-scale constructed wetland site within U.S. EPA Region V and funding of construction, operation and monitoring studies; (2) further detailed literature investigation of commonalties between different types of existing constructed wetlands to determine which features produce optimal treatment effectiveness; (3) investigation of the variation in treatment effectiveness with different soil types; and (4) use of various woody plant species (as opposed to herbaceous emergents) in constructed wetlands as a means of improving nutrient removal, especially for phosphorus.

5.1.2 Impacts on Hydrologic Regime

This issue category was ranked second below constructed wetlands because changes in the hydrologic regime affect all aspects of wetland ecology, as discussed in Chapter 3.0. The hydrologic regime also controls the routes by which water passes through a wetland, thus controlling whether or not losses of relatively untreated wastewater to receiving waters occur. The hydrologic regime must also be understood well enough to determine retention times and loading rates for achievement of optimal treatment. Hydrologic studies conducted at selected sites in Phase II are required as the basis for understanding all other types of impacts, and will therefore contribute significantly to the Generic EIS. Key study topics which should be examined further in Phase II and the rationale for their inclusion are listed in Table 5.1-1.

5.1.3 Long-Term Ecological Impacts

This issue category was ranked highly because wastewater applied to a wetland has a definite potential for altering the structure and function of

Table 5.1-1 Key topics relating to impacts of wastewater on hydrologic regime which should be studied further in Phase II, and the rationale for selecting each topic

Study Topic	Rationale
• Floodwater storage ability	• Addition of wastewater could reduce floodwater storage potential.
• Annual water balance	• Needed to calculate nutrient removal efficiency & to determine potential changes in water budget due to added wastewater.
• Channelization, rates of flow	• Channelization decreases retention time, rate of flow also related to retention time, both affect treatment effectiveness.
• Residence time	• Controls treatment effectiveness, affected by numerous factors.
• Depth, velocity	• Treatment less effective at deeper depths, higher velocities.
• Groundwater connection	• Wastewater could seep into groundwater, avoiding treatment, contaminating groundwater.
• Loading rate	• High loading rate to a small wetland will result in poor treatment effectiveness; optimal loading rate exists for individual wetlands; higher loading rates affect larger areal extent of receiving wetland.
• Discharge timing	• Full year round discharge may have larger impacts in smaller time period than seasonal discharge.
• Areal saturation	• Small seasonal discharge affects smaller total area of wetland, whereas completely saturated wetland may change or be affected more rapidly.

the resident plant and animal communities. Many questions remain, however, with respect to the rates at which such changes occur, the kinds of changes which occur in wetlands of varying types, and the overall changes in value of the receiving wetland as wildlife habitat. In situations where a small discharge is applied to a large extensive monoculture of cattail for example, only localized ecological changes would be expected. In contrast, if a small acid bog were to receive a large continuous discharge of alkaline wastewater, it will eventually be converted to a cattail monoculture, as has been previously demonstrated. Such changes are of serious concern to federal agencies required to protect wetland communities from degradation. However, it has been demonstrated in some cases that wastewater addition may enhance the wildlife value of certain wetlands, such as those previously degraded by other human activities, so that a wetland discharge may be feasible in certain cases. Therefore, knowledge must be obtained concerning the actual long-term ecological impacts of applied wastewater on several wetlands types in Region V in order to provide an improved predictive capability in these situations. Such information could be obtained by continuing research at wetland sites that have been studied over long periods already or by comparing existing ecological conditions of wetlands of similar types which have received discharges over varying periods of time and under different loading rates.

Studies of the long-term ecological effects of wastewater therefore should be given relatively high priority for further information gathering in Phase II. These studies would provide a valuable contribution to preparation of the Generic EIS because of the central importance of the degradation issue. However, long-term ecological effects were ranked below hydrological effects with respect to funding priority, since ecological effects in wetlands cannot be well understood without first understanding the impacts on the hydrologic regime.

General ecological study topics which should be investigated in Phase II and the rationale for each are listed in Table 5.1-2. These topics would have to be further sub-divided in Phase II, but represent what EPA has determined to consist of the major areas of importance.

Table 5.1-2 Summary of ecological study topics to be completed in Phase II, and the rationale for selection of each.

Study Topic	Rationale
• Changes in plant community composition and areal extent	• Wetland could be degraded to lower diversity system, less suitable as wildlife habitat.
• Changes in wildlife population abundance and species composition due to changing water level, changing plant community	• Possibly resulting from changes in plant community; potential loss of valuable wildlife could occur, or in case of previously degraded wetland, enhancement could result.
• Changes in nutrient cycling	• Important to know how wetland removes nutrients, directly relates to treatment effectiveness.
• Changes in loading of other dissolved materials and possible ecological effects	• Effects of chlorine, surfactants, trace metals and similar substances are of potential concern.
• Changes in soil composition and chemistry (soil type, ion exchange capacity, permeability)	• Soil type and chemistry ultimately controls treatment effectiveness of a wetland since most removal is via soil (woody plants may also be significant).

5.1.4 Legal/Administrative/Regulatory Issues

No means currently exists to formally resolve the various legal, administrative, and regulatory issues surrounding the use of wetlands, either as a point of discharge or as a means of treatment of wastewater. Reed and Kubiak (1983) have suggested a procedure for incorporation of the wetland alternative into the 201 planning process. This issue was given priority because of the serious concern expressed by the U.S. Fish and Wildlife Service, various state agencies, and other organizations during the preparation of the present study. U.S. EPA recognized that a means needs to be developed for early planning and good decision making when wetland-wastewater alternative are under consideration. Essentially what is needed is a means to resolve the various conflicts between different agencies and organizations relative to the major legal issues surrounding the degradation question. This will be the key to arriving at mutually agreeable inter-agency decisions on individual permits and monitoring where wetland discharges are involved. There may be specific cases where a wetland discharge may actually enhance a previously degraded wetland. There may also be cases where use of a wetland discharge is an alternative that results in minimizing impacts on an adjacent valuable lake or stream habitat. Further analysis of the legal and administrative issues surrounding wetland discharges in Phase II will therefore contribute significantly to the Generic EIS by providing a first step in understanding the details surrounding these issues.

In Phase II, therefore, U.S. EPA will prepare a technical report which will expand greatly on each of the legal/regulatory and administrative issues discussed in Section 3.9 of the present report. Study topics will include detailed analysis of issues surrounding the Clean Water Act, the Executive Orders on wetlands and floodplains, and all applicable state laws and regulations.

5.1.5 Mitigation/Management Issues

This issue category was determined to be significant because a variety of measures can be taken to minimize the potentially adverse impacts of wastewater on a receiving wetland. Certain management techniques can also be employed to enhance wildlife habitat and simultaneously increase or maintain treatment effectiveness. Key study topics in Phase II which relate to mitigation and/or management, and the rationale for selecting these topics, are summarized in Table 5.1-3. The information developed by further study of these topics will be an important contribution to the Generic EIS since in these cases, the key to inter-agency conflict resolution may be mitigation whether it consists of early planning, actual structural techniques, or wildlife management techniques.

5.1.6 Disease/Health Issues

This was determined to be a major issue because of the potential for transmission of disease or health impacts because of direct toxicity of the effluent to wetland organisms and humans. However, studies of disease-related impacts at wetland treatment facilities to date have shown that such investigations, especially for viral organisms, are extremely costly, and produce results that are hard to interpret. Also, the Houghton Lake studies done to date have indicated that the chemical and physical environment of wetlands is hostile for certain types of viruses, which implies that in some cases the disease problem is not as serious a concern as might be expected. Nevertheless, selected studies should be conducted in Phase II in order to develop an improved understanding of disease and health related issues since the potential for disease transmission does exist and is poorly understood.

Key topics for Phase II should include: (1) studies of viral or bacterial pathogens which could be transmitted between humans and animals; (2) studies of protozoan parasites (i.e., Giardia) and botulism (produced by bacterial pathogen); (3) studies of the effects of wastewater on health and disease problems in mammals; and (4) possible means of disinfecting effluents. All of this information will contribute to the preparation of the Generic EIS by providing an improved understanding of potential disease/health problems associated with wetland discharges.

Table 5.1-3 Summary of mitigation/management study topics for Phase II and rationale for selecting each

Study Topic	Rationale
Management:	
• Wildlife management techniques	• Various techniques are being or have been developed to optimize waterfowl habitat by water level control.
• Fisheries management techniques	• Many important species utilize wetlands as spawning areas or forage habitat; means to optimize fish production, if possible, should be determined.
• Public access/recreation/education	• Means should be sought to optimize wetlands receiving wastewater for recreation or outdoor education.
• Human contact	• If a very large area is involved and there is a concern for human health problems, means to minimize this problem need to be determined.
Mitigation:	
• Planning methods (non-structural)	• Methods of conflict resolution during "201" planning should be developed in detail.
• Structural mitigation	• Measures such as elevated walkways, controlled dispersed discharges, depth control, pre-chlorination, construction under frozen conditions, etc., should be developed.

6.0. FUTURE STUDIES

This final technical report culminates the Phase I efforts in the overall process of preparing a Generic Environmental Impact Statement on the Effects of Wastewater Treatment Facilities on Wetlands in the Midwest. It has presented the results of a comprehensive literature review, a summary of all known wetland discharge sites, and a ranking of the priority study topics to be evaluated at potential study sites. Phase II will encompass the necessary step to develop the information for completion of a Draft and Final EIS. These steps will include execution of a two year effort in gathering field data, publication of an annotated bibliography in cooperation with the U.S. Fish and Wildlife Service, and development of a legal/regulatory requirements document. When these steps have been completed, the scope of the Generic EIS will be defined in more depth based on compiled data, and the Draft and Final EIS documents will be written.

6.1. Phase II Study

6.1.1. Field Work

The field work required to fill the identified data needs will be conducted in two steps. The first step will be to evaluate the sites with high potential for further examination. This step will necessitate site visits to select those sites which have the most merit for Phase II studies and identification of potential cooperative universities or agencies willing to participate in exchange of information. Once the sites have been selected and study teams have been established, the second step will be to conduct the necessary field work over a two year period.

6.1.2. Publish Annotated Bibliography

USEPA Region V will soon publish an Annotated Bibiliography on the Ecological Impacts of Wastewater Application to Wetlands in cooperation with the U.S. Fish and Wildlife Service (FWS). This document will include an annotated bibliography published as part of the draft version of this Technical Report and an expanded search on freshwater wetlands. The new document provides an introduction and background, a listing of abstracts by authors name and an index to subjects, by words, and geographical locations and a study guide for users.

6.1.3. Legal and Regulatory Consideration

Based upon the notice of intent and the scoping meeting for this EIS, a major issue that has surfaced is the legal question and lack of clarity on the use of wetlands for waste treatment. One specific concern is whether this use of wetlands is consistant with the regulations and Executive Orders covering wetland protection. To date, there is little precedent regarding the application of these laws, regulations, or administrative procedures to provide guidance in this area. As part of the Phase II report, EPA Region V will be preparing a technical report on the legal, administrative, and regulatory issues. This document will inventory Federal and state laws, regulations, and procedures and will focus extensively on problem solving and explore different means of possible conflict resolution.

6.2. Preparation of Environmental Impact Statement

When the Phase II studies are completed, EPA will follow up on the scoping of EIS issues that have evolved, and initiate the preparation of the Generic Environmental Impact Statement on the effects of wastewater treatment facilities on wetlands in the Midwest. Additional scoping may occur during Phase II. EPA will publish a Draft Generic EIS for public review and comment, and a Final Generic EIS responding to the input received.

7.0. LIST OF PREPARERS

The USEPA Project Monitor, the WAPORA staff, and the consultant involved in the preparation of this draft report are indicated below.

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APPENDIX A

TECHNICAL SUPPORT DOCUMENT
FOR THE
FINAL TECHNICAL REPORT ON THE EFFECTS OF WASTEWATER TREATMENT FACILITIES ON WETLANDS IN THE MIDWEST

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1.0 INTRODUCTION

This Technical Support Document (TSD) serves as a companion volume to the USEPA report entitled "The Effect of Wastewater Treatment Facilities on Wetlands in the Midwest" prepared by USEPA Region V, Chicago. The purpose of the TSD is to provide an outline and general summary of the scientific methods available to assess impacts of wastewater on wetlands. The methods described are organized according to the general issue and subject categories presented in the main body of the report. These include methods to assess physical (including hydrology), chemical, and biological effects of added wastewater.

The TSD is not intended to serve as a specific approach to designing a research program. It is, instead, designed to serve as a reference source of the possible range of methods which are available to study specific types of impacts. The overall design of a particular individual study must be decided upon by the researchers who actually are to conduct the detailed site studies in the Phase II of the present project. However, the TSD does provide general discussions and outlines of the types of studies as well as rough estimates of the level of effort (in man-hours or man-days) that could be required to complete each study. Proposed sampling schedules are also included. Again, this information is intended as a useful guide for the Phase II research.

2.0 METHODS

2.1 METHODOLOGIES FOR INVESTIGATION OF EFFECTS ON SITE HYDROLOGY AND LOCAL WATER TABLE

Interactions between the numerous hydrological and chemical components of the wetland ecosystem are complex. Also, some of the techniques required for investigation in wetlands are difficult to implement. Therefore, the methodologies for investigation of the issues decribed in this section are presented as text discussions only. A summary of the tasks to be performed and the time frames for these tasks is included in Table 2.1-1.

The overall objective of the hydrological study at each site chosen should be to determine the water budget. This information will form the basis for the interpretation of the transport of all suspended and dissolved materials, and therefore is an important research requirement at every site.

The major input and output routes for the passage of water and waterborne materials through a wetland ecosystem are diagrammed in Figure 2.1-1. Several approaches can be used to study the movement and fate of these parameters including the following:

- Consideration of the entire wetland as a unit within which processes occur but are not investigated; only the inputs to and outputs from the wetland as a whole are measured (the "black box" approach)
- Investigation of the changes that occur in the water (differences in water quality parameters) along the path of its passage through the wetland (the "transect" approach)
- Measurements of processes in which the constituents of wastewater are involved within the various parts of the wetland (the "compartment" approach).

The first method considers the wetland as an entire system; the latter two techniques are subsystem methods. The hypothetical boundaries used in each approach are shown in Figure 2.1-1.

In order to obtain sufficient information for analysis, it will be necessary to collect and analyze data on storages and flows on a monthly basis

Table 2.1-1. Proposed sampling schedule for hydrological and water quality investigations.

Parameters to be Sampled/Technique	Frequency of Sampling				
	Once	Daily	Weekly	Monthly	Annually
Hydrology					
Precipitation			X		
Evapotranspiration			X		
Water level					
Stevens recorders			X		
Staff gauges				X	
Piezometers (surface water and groundwater)				X	
Water velocity and direction					
Current meters				X	
Tracer techniques (surface water and groundwater)				X	
Inflow					
Facility daily flow recordings (collect if available)				X	
Meter devices				X	
Outfall					
Meter devices				X	
Gradient survey	X				
Depth/area and channelization	X				
Flushes	X (daily during event)				
One major rain event (possibly in May)		X (during event)			
Soil samples					
Water capacity	X				
Diffusion/penetration tests	X				
Nutrients					
Phosphorus, nitrogen, sulfur analysis					
Water					
Grab samples				X	
Transects	X				
Vegetation					
Grab samples (or plots)					X (autumn)
Transects					X (autumn)

Table 2.1-1. Proposed sampling schedule for hydrological and water quality investigations (continued).

Parameters to be Sampled/Technique	Frequency of Sampling Once	Daily	Weekly	Monthly	Annually
Litter bag harvest-transects				X	
Grab samples					
Algae and sediment					
Input/outflow (I/O) point samples				X	
Sediment traps-grab samples				X	
Transects				X	
Soil samples					
0-5 cm sample					X (autumn)
Transects-soil core					X (June)
P-sorption sample	X				
Flushes	X (daily during event)				
One major rain event (possibly in May)					
I/O water for N, P		X (during event)			
Litter bag harvest for mass N, P, S		X (during event)			
Litter grab samples for N, P, S		X (during event)			
Sediment grabs for N, P, S		X (during event)			
Other Dissolved Substances					
Chloride ion, electrical conductivity, calcium, magnesium, pH					
I/O water measurements				X	
Water transects					X (June)
Flushes - daily I/O water	X (daily during event)				
One major rain event		X (during event)			
Dissolved organics - COD, BOD					
I/O water measurements				X	
Water transects					X (June)
Flushes - daily I/O water	X (daily during event)				
One major rain event		X (during event)			
Dissolved oxygen					
I/O water samples				X (unfrozen season)	
Transects					X

Table 2.1-1. Proposed sampling schedule for hydrological and water quality investigations (concluded).

	Frequency of Sampling				
Parameters to be Sampled/Technique	Once	Daily	Weekly	Monthly	Annually
Toxic Elements					
Heavy metals concentrations					
Locate where materials occur	X				
o Standard wet chemical methods					
o Neutron activation analysis					
o Atomic absorption spectroscopy					
Grab samples of the following compartments along the same transects:	X				
o I/O waters					
o Transect waters					
o Litter					
o Sediments					
o Suspendable solids					
o Soil samples					
o Algae					
o Vegetation					
Refractory chemicals					
I/O waters	X				
Transects of the following compartments:	X				
o Litter					
o Sediments					
o Suspendable solids					
o Soil					
o Algae					
o Vegetation					
Soils and Sediments					
Soils					
Read soil staff gauges				X	
Borings	X				
Probings	X				
Core samples for Ce-137, Pb-210, C-14	X				
Leaching and diffusion tests	X				
Sediments					
I/O water grab samples of:					
o Suspended solids				X	
o Volatile suspended solids				X	
Suspendable solids samples (taken at established interior stations)					X
Sediment traps				X	

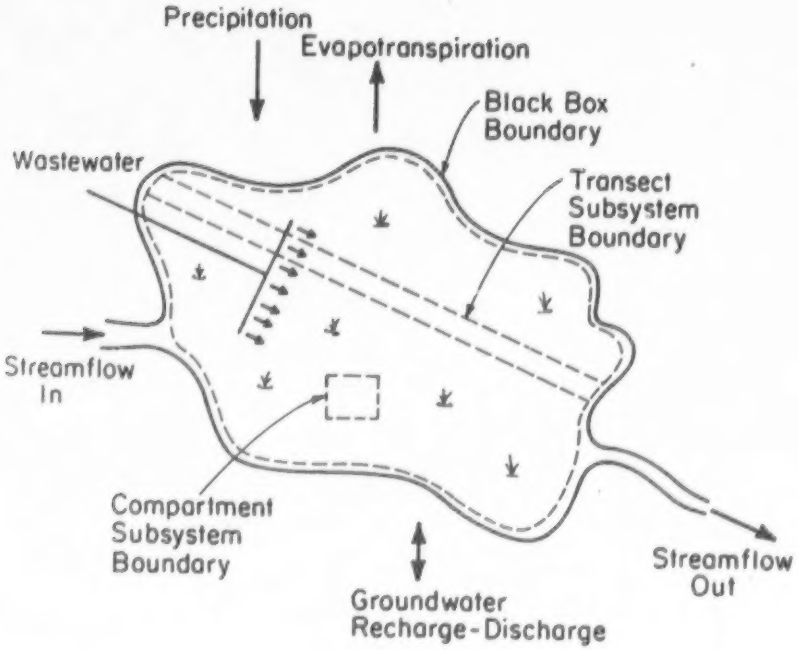
Precipitation
Evapotranspiration
Black Box Boundary
Wastewater
Transect Subsystem Boundary
Streamflow In
Compartment Subsystem Boundary
Groundwater Recharge-Discharge
Streamflow Out

Figure 2.1-1. Components of a hydrological investigation of a hypothetical wetland (adapted from Kadlec 1980).

during the study period. Measurements should include precipitation and evapotranspiration, as well as net surface and subsurface flows and selected individual flows within the wetland. Chloride and conductivity, and possibly dissolved substances such as calcium and magnesium, should be used as tracers to confirm flow measurement or to infer subterranean flows. This information then is analyzed to formulate mass balances for water on a monthly basis during the study period.

In addition to these general water balance studies at each site, it would be desirable to collect and analyze data on storages and flows for brief intensive periods. These studies would ascertain the magnitude of diurnal (daily) and other short-term processes at a particular site. Thus the impact of a sudden heavy rainstorm on water depths and flows, and the associated water chemistry, would be helpful to answer questions related to flushing. One of these intensive periods should be done during the spring flush; another during autumn.

2.1.1 Measurement Procedures

Streamflows can be measured with current meters for major flows, and by tracer techniques for minor flows. Both a cross-sectional area of flow and the velocity distribution in the stream in question are required to develop an estimate of the volumetric flow rate by either method. Thus it is imperative that the boundaries around the wetland that are crossed by inflow and outflow streams are well defined, so that there is no ambiguity about the area of the flowing stream. Some sites are already equipped with some form of controlled area outflow device. For example, the Drummond WI site utilizes a V-notch weir through which all outflow passes. Other wetlands will have inflows and outflows through road culverts. This is a very common boundary for small wetlands in the upper Midwest. In such cases, the area is measured easily, and a velocity can be obtained by the movement of a tracer, such as a neutral density object, through the culvert itself. The distance and time of transit would provide a measure of speed of flow through the culvert. The average velocity is approximately half the maximum centerline velocity in such a situation. This fact may be used to obtain fairly good estimates of inflows and outflows in situations where there are no weirs or other flow-measuring devices.

Diffuse overland flow inputs and outputs are nearly impossible to measure with any degree of accuracy, and it is necessary to use secondary methods in order to obtain estimates of inflows and outflows in such situations. One technique that may be applied is to compare evaporation losses from a pan of water, as measured with a continuous water level recorder, to the water level changes in the wetland. The water level in a properly placed Class A pan will ultimately drop due to the competing processes of evaporation and precipitation. The water level in the wetland itself will drop due to the same processes, but in addition also will drop due to the net outflow from the wetland. The difference between inflow and outflow. This net added effect may be due to surface streams or to recharge/discharge processes. In situations where streamflow is absent, the use of a pan will give a measure of recharge/discharge. In the case of a perched wetland (that has no surface connection to another water body and lies above impervious bedrock, till, or a small pocket of outwash overlying till), the use of a pan will provide a measure of the inflow minus the outflow to that wetland. This technique is limited by the assumption (fairly well accepted) that evaporation and evapotranspiration are nearly equal over a significant area. Thus evaporation in the pan would be comparable to evapotranspiration in the wetland (Scheffe 1978).

The use of a Stevens recorder to measure water levels will provide a measure of the storage of water within the wetland, when accompanied by an estimate of the areal extent of the amount of freestanding water within that wetland. In cases where freestanding water does not exist, some measurement of the field capacity of the wetland soil for water retention would be required in addition to the measure of areal extent. For example, if 50% of the soil volume is available for water storage in a particular wetland, then that measurement is needed to accompany the number of acres of water storage available. Information on the total size of such a storage pool is necessary for interpretation of the retention time of waters within that wetland.

Measures of precipitation and evapotranspiration can be obtained by standard meteorological techniques. Evapotranspiration can be measured either with a Class A evaporation pan maintained at each site, with the level in the pan being monitored, or from level recorder charts. Precipitation data can be obtained from rain and snow gauges placed at the same location as the pan. If such accurate direct measurements are not required, evaporation can be estimated by either the Penman (1956) method or the Thornthwaite (1950) method. Both have been proven to be effective in estimating evapotranspiration in wetland situations.

Data on the areal extent of the wetland and the average thicknesses of snow and ice cover are required to estimate the total amount of water stored in these two solid forms. Such data frequently are available at neighboring weather stations for snow depth, but ice depth measurements must be taken inside the wetland to be accurate. Ice depths in wetlands frequently are much less than they are on open water bodies or on the neighboring mineral soils; ice thickness may vary as much as two orders of magnitude in the upper Midwest. In many instances, the wetland surface does not freeze, even during the harshest winters.

Connections between the wetland and underlying aquifers can be inferred through tracer studies, which may involve the use of calcium, magnesium, or chloride as an indicator. Data obtained from these experiments may be corroborated by readings taken from piezometers placed in and around the wetland at points of communication with these underlying aquifers (a piezometer is an instrument used to measure pressure as height of water in a pipe). Data on the underlying soil types also may be used to determine the probable rates of water movement. This would provide a measure of permeability and possible communication with groundwater.

Flow through a wetland is largely controlled by channels. Well-defined river channels flow through some wetlands, while movement of water in others is primarily surface sheet flow. The extent of channelization would be an extremely important variable in interpreting the performance of a particular wetland receiving wastewater applications.

Vertical slope is also an important variable since it determines the driving force for movement of water through the wetland. Although many wetlands are essentially flat, some of the sphagnum bogs in the northern parts of Region V are tilted at relatively large angles (10 to 20 feet per mile). Information on vertical slopes could be obtained most easily during the winter months through standard surveying techniques.

The last water quantity parameter of interest is the amount of pumped wastewater added to the wetland. In some cases, information may be available on daily flows entering the wetland from the wastewater treatment facility. In instances where such information is not available, it would be necessary to install a metering device, such as a turbine meter, a weir, or a flume, to obtain accurate measures of the flows entering from the facility.

2.1.2 Typical Site Investigation

During the initial visit to the site, the points of entry or exit of all inflows and outflows would be determined. The gradient of the wetland would be surveyed. The percent channelization, as measured by the distribution of depths transverse to the general flow direction, would be determined. Staff gauges for recording water levels would be installed at various points. The method for measurement of streamflow at each location would be determined, and the appropriate equipment or devices subsequently would be installed to measure those flows. Class A evaporation pans could be installed at several locations. Piezometers could be installed if communication with groundwater was confirmed by a small set of subsurface borings to identify the underlying strata. Both the areal storage parameter fraction of open water and the field capacity of the wetland soils would be determined on a one-time basis. Rain gauges and water level recorders would be installed at those locations where it was deemed necessary. The amount of effort involved in this survey and instrument set-up would be approximately two person-weeks per site, at the most intensive level.

Routine data collection at each site probably would require approximately one person-day per week. This time would include reading and changing of charts on water level recorders, reading staff gauges and piezometers, collecting samples for tracer studies, and reading stream flows. The analysis of the tracer samples for chloride, calcium, magnesium, and conductivity would require approximately one person-day per month for laboratory analyses. Correlation and analysis of the data obtained during the weekly field visits and the laboratory tracer analyses would require approximately one person-da per month.

The spring and autumn flushing events and the storm events would be studied at the time of occurrence. The amount of effort involved in determining the water budget for a precipitation event at a particular wetland might include four days of field work, two days of laboratory work, and one day of analysis.

The procedures described above are presented in greater detail in the studies of Odum in Florida, Kadlec in Michigan, and Kappel in Wisconsin (see site summaries in Appendix B). It must be stressed that every quantitative aspect of understanding of the performance of the wetland (biotic or abiotic) is dependent on an understanding of the hydrologic processes. Therefore, the hydrological studies are perhaps the most important and basic of all of the methodologies for understanding the effects of the addition of wastewater to wetland ecosystems.

2.2 METHOD FOR INVESTIGATING PHOSPHORUS LEVELS

Levels of phosphorus in municipal wastewater are much higher than background levels within wetlands. Levels of phosphorus in municipal wastewater are typically in the range of 1 to 10 milligrams per liter (mg/l), while those in natural wetlands (water column) generally are less than 0.1 mg/l. Phosphorus levels in sediments, plant tissues, and soil are likely to be a few tenths of 1%. These forms of phosphorus are immobile and are affected by processes of sediment accumulation and soil decomposition. However, they are not affected by transfers from the dissolved phosphorus in the water column. Only a relatively small pool of adsorbed phosphorus, contained on the surface of sediments and other wetland solids, is exchangeable with the water.

Two types of studies are of importance in assessing the state and function of a wetland receiving phosphorus inputs in the form of wastewaters. The objective of the first is to gain an understanding of the total system performance including the amount of the phosphorus entering and leaving the wetland and the resulting accumulated pool within the wetland. Both dissolved and particulate forms of phosphorus are important in this analysis. The methodology for establishing the phosphorus balance for a particular wetland will depend primarily upon the hydrology of that ecosystem. It is presumed that the hydrologic budget will be determined for any site at which phosphorus balance is to be established. In addition to hydrologic measurements, analyses of the total phosphorus levels of the incoming, stored, and outgoing waters must also be conducted. A detailed example can be found in Kadlec (1980).

Three forms of phosphorus can be important at any particular wetland location. These include dissolved orthophosphate, other dissolved forms, and phosphorus associated with sediments and other suspended solids. Methods of analyses for total dissolved phosphorus and total phosphorus are described in American Public Health Association (1976). Analysis for orthophosphate alone probably is not worthwhile, since this form is only slightly more available than other dissolved forms. Measurement of total dissolved phosphorus provides the most useful information relative to determining impacts of wastewater application. If significant amounts of suspended solid material (more than 10-100 mg/l) are measured at any one location, special procedures for analyzing the solids also should be performed. At this level, it becomes important to know the precise content of the solid material, since significant amounts of phosphorus are involved.

In urban industrial regions, contribution of P from rainwater can be significant, and should be included in preparing the nutrient budget. For example, P levels of over 100 mg/l in rainwater from such areas are common (Benforado 1981).

The second type of study required concerns internal phosphorus cycling. Phosphorus is cycled internally through emergent vegetation by processes of uptake, incorporation into tissues, litter fall, litter decomposition, and soil building. It also is cycled through algae and mobile sediments within the wetland by processes of uptake, decomposition, sedimentation, and soil building. . Phosphorus is also cycled via sorption and desorption from soil surfaces. These processes are accompanied by the diffusional penetration of dissolved phosphorus into the water within the soil.

Cycling of phosphorus through emergent vegetation has been studied at a number of sites (Pratt et al. 1980; Prentki et al. 1978). In some studies phosphorus was shown to be incorporated into plant tissues at levels that did not vary greatly with the amount of available phosphorus in soil water in the root zone. In other studies (i.e., Ewel and Odum 1979) workers found good correlations between tissue nutrient levels and soil nutrient levels. In any event, measurements of biomass of the above-ground and below-ground plant parts at the end of the growing season provides an accurate assessment of the "living tissue" phosphorus compartment of the wetland. This information, together with data on productivity, will allow estimates of the rate of incorporation of phosphorus into living emergent vegetation. The procedures for such analyses include the ashing of weighed samples of ground and dried plant material and the analysis for phosphorus according to standard methods (American Public Health Association 1976).

A significant amount of phosphorus taken up by emergent vegetation is eventually released during decomposition of dead plant material following senescence. This process can be measured by employing the litter bag method. This method is described in detail in Chamie (1976) and discussed further in Section 2.8.4 of this report. In general, a known amount of litter is placed in a fine mesh bag at a location from which the litter was taken. The bags can be harvested at varying time periods in order to determine the rate of decomposition and phosphorus content.

Pathways of phosphorus movement that involve algae and sediments are more difficult to quantify. It is probable that there are significant uptakes of phosphorus by algae, and significant returns of this material to the water upon death and decomposition. Some phosphorus is also immobilized in algal tissue and deposited as sediment on the litter-soil interface. Analysis of samples taken at the inflow and outflow points of the wetland will permit measurement of the net amounts of phosphorus that enter or leave the wetland. Some measure of the amount of suspended particulates (including large portions of plants) that may be movable within the wetland would also be valuable since major storm events (i.e., a 20-year rainfall) might move significant quantities of these materials. Therefore, it is recommended that a standardized method for agitating the litter-sediment zone of the wetland and for collecting samples of the materials thus suspended be established. These samples should be analyzed for both total mass and phosphorus content. Measurements along a grid transect in the direction of flow also should be made to determine the rate at which such suspended solids are transferred down the hydraulic gradient.

The sorption/desorption processes that occur at the soil-water interface constitute a significant physical and chemical mechanism for phosphorus immobilization. Sorption is known to occur rapidly, and form the first storage pool in a given wetland. Net sorption ability by sediments thus is an important factor which determines the ability of a specific wetland to treat applied wastewater. Some information exists in the literature on the capability of wetland soils to immobilize phosphorus in this manner (Hammer and Kadlec 1980; Nichols 1979a,b,c). Information on the capacity of specific wetland soils to accumulate phosphorus is not generally available at this time, however. It is recommended that a laboratory study be made of the phosphorus sorption potential for each primary wetland soil type. Such tests should include both the ultimate capacity of the soil sample taken and the rate at which phosphorus can penetrate and be absorbed into the sample. In actuality this is only one test, because rate data can be acquired during the process of establishing the capacity for phosphorus sorption.

Desorption studies are much more difficult to conduct although several techniques have recently been proposed (Richardson et al. 1978). The test basically involves analysis of distilled water extracts of phosphorus-laden soil and sediment samples. This would permit determination of the amount of exchangeable phosphorus which potentially could be returned to the water column.

2.2.1 Typical Site Investigation of Phosphorus Balance

The phosphorus balance studies described above would be conducted simultaneously with the hydrologic studies and at the same sampling locations and sampling frequencies. The samples would be analyzed for total dissolved phosphorus (and possibly other forms). A total of approximately one person-week per year would be needed for determination of the phosphorus budget data. Analysis of the information obtained would require approximately one person-week per year (per wetland).

Analyses of tissue samples in order to quantify the plant uptake/litter pathway are more difficult. Wet ashing of the samples is time-consuming. However, these procedures would have to be performed on grab samples of vegetation only once per year at each wetland. Sample collection would require an effort of one person-day per year. Samples analyses in the laboratory would require a total of one person-week per year. Data analysis should require two person-days per year per wetland.

Tests on the soil compartment would involve approximately one week of laboratory work per wetland, in order to establish the rate of phosphorus uptake, the equilibrium capacity for phosphorus sorption, and the desorption rate. Analysis of sediment nutrient content could be accomplished in a manner similar to the litter analysis. A comparable amount of time would be required for this task.

In summary, the analysis of the phosphorus cycle of a given wetland ecosystem consists of examining the major pathways in enough detail to understand whether or not there are anomalous pools or transfers. The principal focus would be on uptake by plants, litter fall, and litter decomposition; sediment transport and sedimentation rates; and soil sorption processes. This information would be used to establish the phosphorus budget for a given wetland.

It may be desirable at certain sites to determine potential anomalous behavior of the water and sediment exchanges during periods of extensive precipitation, including the spring and autumn flushings. Such intensive studies of isolated events would require the attention of a single researcher for some two or three weeks (per wetland), and a comparable time period for laboratory analysis. These measurements should be conducted simultaneously with the hydrology studies.

Because phosphorus is one of the principal regulated quantities associated with wastewater discharges, an understanding of its transport and accumulation is of major concern to regulatory agencies. Phosphorus also is a prime driving force in the wetland plant community, and therefore represents one of the most important pollutants associated with municipal wastewater discharges.

2.3 METHODOLOGIES FOR NITROGEN INVESTIGATION

The objectives of the nitrogen investigation are similar to those for phosphorus, although there are major differences in the cycling of these two elements in wetlands. First, nitrogen cycling involves several microbial interconversions between nitrate, ammonia, and gaseous forms of nitrogen that do not occur in the phosphorus cycle. The soil-water interface is therefore also an important zone of study for nitrogen processes. Furthermore, levels of nitorgen in plant tissue are usually one order of magnitude higher than phosphorus. Levels of nitrogen in the incoming wastewater are likely to be of the same order of magnitude as phosphorus levels (perhaps only slightly higher in most instances). Ammonia and nitrate levels in incoming municipal wastewater typically total approximately 10 mg/l. Concentrations of nitrogen in soil, sediment, and litter compartments are likely to be approximately 2% by dry weight, similar to that for plant tissues. Thus the size of the potential storage pool in the form of biomass, soils, and sediments is much larger for nitrogen than for phosphorus. However, nitrogen may be removed by microbial denitrification, a process which occurs under anaerobic conditions. Sorption and desorption of nitrogen compounds upon soils and sediments is not generally considered to be an important process.

The system level of analysis is useful in determining the effects of applied wastewater on the nitrogen balance in wetlands. Measurements of nitrogen levels in water entering and leaving the wetland should be taken in conjunction with hydrologic measurements. This allows determination of the amounts of various forms of nitrogen entering and leaving the wetland in the form of dissolved and suspended materials. Grab samples of incoming and outgoing waters should be analyzed for nitrate, ammonia, and total nitrogen. If significant amounts of suspended solids (100 mg/l) are noted, then an analysis of the solids themselves should be performed. Grab samples of surface waters along a transect also should be taken for similar analyses. Standard methods are available for these particular dissolved constituents (American Public Health Association 1976). An alternative method is the use of specific ion electrodes for nitrate and ammonia. These procedures are much more rapid but not as accurate. The concentrations determined through the above analyses, when multiplied by flow provide an estimate of the amount of nitrogen entering and leaving the wetland and the amounts within the water storage pool. Nitrogen also passes from the wetland into the atmosphere in the form of nitrogen and nitrous oxide. These losses are extremely difficult to measure, however, and constitute a largely unknown quantity. Although there are also inputs of nitrogen compounds in the form of precipitation, these generally are negligible.

The pathways of nitrogen cycling within the wetland also may be used to study the effects of applied wastewater. The nitrogen pathway through emergent vegetation includes uptake, incorporation into the plant tissue, litter fall, and litter decomposition. Procedures for obtaining grab samples of the foliage, and roots, and litter would be the same as for phosphorus. These materials can be analyzed in the laboratory by wet ashing, followed by chemical analysis by standard methods or specific ion electrodes.

The role of suspended solids and algae should be determined in the same way as for the phosphorus cycle. Again, the major variables to be quantified are the amount of suspendable material and its nitrogen content. These data will provide an understanding of the potential for the flushing of particulate material from the wetland. When coupled with the results of transect measurements, this would provide an understanding of the net movements that are occurring.

Soil sorption processes are not thought to be important in the case of nitrogen compounds, but denitrification is important. Currently there is no standard laboratory technique that can be used to predict the field characteristics of a soil and its microbial population to allow estimation of the process of denitrification. This process can be understood only from inferences gained from transect measurements of water chemistry along the hydraulic gradient within the wetland. Measurements of Redox potential (eH) in the upper soil layers would provide some basis for understanding denitrification, since conditions for this process are optional between eH values of +100 to +200 millivolts. Measurements of water depth and oxygen content of the overlying water column also provide insight into the ability of a wetland to denitrify.

2.3.1 Typical Site Investigation of Nitrogen

Determination of the nitrogen budget and the internal processes of uptake and transfer will require monthly sampling intervals. Sampling should be conducted simultaneously with hydrologic measurements. Approximately half of a person-day per month should be sufficient for the collection of samples. Studies of the nitrogen budgets of individual ecosystems will require more field time than similar studies of phosphorus budgets. Obtaining transect data to estimate denitrification would involve approximately two person-days per month for each wetland. Sediment samples, plant biomass samples, and litter bags would require an additional two person-days per month. The three potential flushing events (spring, autumn, and one additional major storm event) should be sampled in conjunction with the hydrologic and phosphorus studies. This would entail up to several person-weeks per wetland site, with the balance of this time being devoted to related studies. Sample analysis would require a total of three to four person-weeks per year per wetland site to accomplish all of the nitrogen studies described above. The laboratory effort is slightly greater than that required for phosphorus because more forms of nitrogen must be examined.

It is recommended that cores from the soil column be partitioned into five-centimeter intervals and analyzed for nitrogen at several stations to infer the past history of nitrogen events at that particular wetland. This analysis would require a total of approximately one person-week of effort for collection, analysis, and interpretation of the data.

In summary, studies of nitrogen compounds within the wetland are extremely important from the regulatory point of view (for reasons such as the toxicity of ammonia to fish and potential to stimulate eutrophication). Every wetland receving wastewater that has been examined to date has appeared to effectively remove nitrogen. This function requires further understanding, because background studies are not as complete for nitrogen.

2.4 METHOD FOR INVESTIGATING OTHER DISSOLVED SUBSTANCES

2.4.1 Dissolved Oxygen

Dissolved organics (as measured by COD and BOD) may greatly reduce dissolved oxygen levels in the water column of a wetland. This in turn can hinder important wetland processes such as denitrification or lead to death of fish and invertebrates. Little is known, however, concerning the effect of increased COD or BOD on wetlands. Tests for dissolved oxygen can be accomplished by the use of portable field meters. Laboratory analyses for COD and BOD are described in American Public Health Association (1976).

The level of dissolved oxygen also is a strong indication of algal activity. Because of the correlation of algal photosynthetic and respiratory periods with light availability, dissolved oxygen levels may vary from nearly zero to nearly double the saturation capacity of the wetland water at a given site. This factor must be considered when estimating effects of added wastewater on oxygen levels.

2.4.2 Sulfur

Because wetlands are known to play an important role in the cycling of sulfur and because increased sulfur levels could be directly toxic to wetland plants and aquatic animals (Odum 1976), investigation of the effects of wastewater on sulfur cycling and sulfur levels would be desirable. Tests for sulfites and sulfides are difficult to make because current sampling procedures result in the rapid oxidation of these materials. However, concentrations of sulfates and sulfur can be analyzed easily. The sulfur content of selected wetland ecosystem compartments can be assayed with the use of a sulfur analyzer (for example, a LECO analyzer). Sulfur concentrations within wetland plants are likely to be within the range of 0.5% to 1.0%. Comparable levels will exist in the litter and soil and sediment compartments.

Measurements at a given wetland site should be restricted to a one-time sampling of biota and soil sediment and litter compartments, coupled with a one-time assessment of the sulfate status of the waters entering and leaving and within the wetland. Samples should be returned to the laboratory for analysis of the sulfate content of the water. The total effort to be expended at a single site for both field and laboratory work would be approximately two person-days per month. Determination of the rate of release of sulfur in the form of hydrogen sulfide (or other similar compounds) that occurs during anaerobic periods (usually winter) and assessment of the amount of sulfur arriving in the form of acid rainfall are beyond the scope of this study.

2.4.3 Chloride

Measurements of chloride concentrations should be coupled with measurements of electrical conductivity and concentrations of calcium and magnesium. Chloride can be measured with the use of a specific ion electrode and conductivity with the use of an electrical conductivity meter. Chloride measurements are valuable, however, for confirmation of the water budget for a particular wetland and for estimation of unmeasurable flows. This is accomplished by measuring the difference between concentrations at different locations. Levels of chloride in municipal wastewaters are typically one order of magnitude higher than those in natural wetland waters, most naturally-occurring shallow groundwater systems, and in precipitation and surface runoff. The use of such indicators would not be possible where road salt has been allowed to enter the wetland. Even if detailed overall nutrient budgets or water budgets are not desired at a particular site, chloride could be used as an effective tracer to estimate the dilution of the wastewater in its passage through the wetland.

2.4.4 Conductivity

Conductivity measurements could be interpreted in much the same way as chloride concentrations. However, sources and sinks would be much more complicated in most wetland situations because all of the dissolved species in ionic form contribute to this measurement. Conductivities of wastewaters typically are much higher than those of the receiving waters in a natural wetland. Therefore, this parameter may also be used as a measure of dilution or to infer inflows and outflows to a wetland that are difficult to measure.

2.4.5 pH

The acidity or alkalinity of a wetland water column, as measured by pH, can be used to measure key wetland processes such as the possible chemical erosion of an organic soil. This parameter also is a major factor in the control of the types of vegetation that occur within a given wetland. Measurements of pH can be made in either the laboratory or the field.

2.4.6 Typical Site Investigation of Dissolved Substances

It is recommended that chloride, magnesium, calcium, conductivity, and pH be measured routinely at all water quality sampling sites. These measurements would typically require approximately one-half of a day per month for field work and one-half of a day per month for laboratory analysis.

For COD and BOD it is recommended that measurements of inputs and outputs be made over a period of a year. In addition, transect studies of these quantities should also be conducted. These data would be used to define the annual performance of the wetland in altering the dissolved organic content of the waters. The samples can be acquired during other water sampling activities and returned to the laboratory for analysis. Field sampling should require approximately one-half of a day per month at a given site, and the laboratory work would require approximately one day of effort for every 12 samples.

2.5 METHODOLOGIES FOR INVESTIGATION OF THE EFFECTS OF POTENTIALLY TOXIC TRACE METALS

Trace metals will not be a major issue at all wetlands receiving applied wastewater. However, some sites were identified at which elevated levels of trace metals were being discharged into a wetland. Only those sites identified as suitable for such investigations on the basis of information from regulatory personnel would constitute candidate sites for the study of this issue.

The necessary studies would involve measurement of the quantities and of specific trace metals within each wetland. Trace metal concentrations should be measured in both the incoming and outgoing waters and in the various soil and vegetative compartments. These compartments would include sediments, soil, algae, and emergent vegetation. Levels of trace metals in invertebrates and fish should also be studied (refer to Section 2.8.8 for descriptions of methodologies for determination of the effects of trace metals on animal populations). In addition to the standard wet chemical methods (American Public Health Association 1976), two important and convenient methods are available for the determination of the elemental constituents in a solid or liquid sample: neutron activation analysis and atomic absorption spectroscopy. With the neutron activation procedure, the concentrations of some thirty elements, including mercury, cadmium, nickel, zinc, and arsenic, can be measured in either a solid or a liquid sample. The detection limit for each individual material depends upon the nuclear structure of that element. Copper, lead, and boron, which may be elements of interest for this study, cannot be measured by neutron activation analysis procedure at present. However, these can be measured by atomic absorption spectroscopy. Because only one element can be measured during each analysis, this procedure is more time-consuming than neutron activation analysis. However, neutron activation analysis is expensive. Facilities for neutron activation analysis exist in Ann Arbor MI and in Missouri. Many laboratories in USEPA Region V can perform atomic absorption spectroscopy. Wet chemical methods can be done in any well-equipped chemical laboratory.

The present state of knowledge is too limited to permit the investigation of the routes of transmittal of trace metals from one compartment of the ecosystem to another. Therefore, an inventory should be made of the compartments which accumulate these elements in wetlands of different types that receive varying quantities of trace metals.

2.5.1 Typical Site Investigation of Potentially Toxic Trace Metals

Other than the data that may be collected during the site surveys, no prior field work would be required for this study. At a convenient point in time (ideally during the growing season) grab samples should be collected and analyzed. These would include samples of the incoming and outgoing waters, as well as water samples taken at various points within the wetland between the inlets and outlets. Grab samples of the suspendable solids, soil, algae, and emergent vegetation should be taken along the same transects. Both living plants and detrital material should be sampled. In sampling root material, the submerged portions of plants must be washed carefully in order to eliminate the important surface films of nonplant material (Lee 1975).

The concentrations of trace metals obtained through analysis of the samples can then be combined with information on flows, hydraulic storages, and above-ground productivity of vegetation. This will yield estimates of the quantities of trace metals that have accumulated in various portions of the wetland and the pattern of their distribution.

Approximately one person-day per site would be sufficient for collection of samples of the major compartments. The majority of the effort for this investigation will be required for the laboratory analyses and data interpretation.

The procedures referred to above have been documented in greater detail by Lee et al. (1977), Lunz (1978), and Banus et al. (1975). Similar types of studies have been performed at two sites in Florida, two sites in Ontario, one site (a salt marsh) in Massachusetts, and one site in Michigan.

2.6 METHODOLOGIES FOR INVESTIGATION OF THE EFFECTS OF REFRACTORY CHEMICALS

If one or more sites are identified as receptors of industrial or agricultural chemicals, a study of the fate of these materials would be useful in assessing the impact on wetlands or the ability of the wetland to process these materials. However, analytical procedures for these complex molecules are difficult and specialized, and the concentrations of the chemicals are very low.

The investigation should be carried out on a one-time basis for several sites. Measurements should be made of the water entering and leaving the wetland. Because of the expense of the analytical procedures involved, it is suggested that no more than a few (ten to twelve) of the more likely chemicals of interest be investigated.

2.7 METHODOLOGIES FOR INVESTIGATION OF EFFECTS ON SOILS AND SEDIMENTS

2.7.1 Soils

Two broad categories of experiments and studies should be performed on the soil compartment. These include (1) determination of the changes in type and quantity of the existing soil; and (2) the incorporation of elements such as phosphorus into the soil. To establish baseline conditions, it is desirable to first obtain data on the underlying soils at each wetland site selected for study. Intermediate depth soil borings to approximately 35 feet should be performed to identify the underlying strata at each site. This information is needed to determine the major hydrologic features of the wetland, since little communication with groundwater will occur if impermeable soils are located beneath the site. On the other hand, the presence of porous soils in the lower horizons may be an indication of significant communication with underlying aquifers. These same borings also can be used to define the depth of the upper wetland soil horizon (probably organic in many cases). It would be desirable to probe the depth of the uppermost soil horizon at several locations. Because only approximately the top meter of soil is likely to be active in the wastewater treatment functions of the wetland on a long-term basis, it would be feasible to probe a significant number of locations to determine soil type and status.

The processes that can affect the type and amount of soil present in a wetland include sedimentation, litter fall, erosion, and chemical leaching. The question of erosion is unlikely to be of significance at wetland sites in Region V, although erosional processes due to wastewater addition have been observed to be extremely important at other locations, such as the Las Vegas Wash (Tusack-Gilmour 1980). At that site, losses of wetland due to erosional processes have totalled several hundred acres over the period of a few years. (Information on this site is given in Appendix B.)

Processes of litter fall are defined in connection with the measurements of productivity of the vegetative community (Section 2.8.3). Productivity places an upper limit on the amount of detrital material that can reach the litter compartment in the wetland during the growing season. This information, combined with data on litter decomposition, will provide an estimate of the rate at which the plant material is contributing to the process of organic soil building. The companion process of sedimentation may result from deposition of organic or inorganic materials suspended in flowing waters. Materials from natural origins are present in the inflows to the wetland, and both inorganic and organic materials from the sewage treatment plant also will enter the wetland. The production of algal detritus is another internal source of suspendable material that may move from one location to another in a specific wetland. All of these processes result in a net increase in the soil within the wetland.

The process of chemical leaching may decrease the amount of soil within a wetland. Organic soils are typical of a large number of wetlands and can be dissolved to a significant extent by waters with a high pH. Consequently, wastewater with a high pH potentially can dissolve significant quantities of organic material. This phenomenon has been observed at some wetland sites, such as at Kincheloe MI.

Each of these processes is worthy of further understanding and study at the selected sites. The overall processes of soil building and destruction can be inferred through two different types of soil measurements made at each wetland. These include: (1) a simple mechanical measure of the top of the soil horizon; and (2) radiotracer techniques. The mechanical method is done by comparing measurements from staff gauges anchored to the lower mineral soil horizon and to the root mat in the upper soil horizon. Such gauges can be installed easily and may be read on a routine basis. The radioactive tracer techniques are similar to those described previously. For example, cesium-137, a radionuclide with a half life of 30 years, has no natural occurrence but was introduced into the environment as a result of nuclear testing. For about the last 30 years there has been a varying deposition of this radionuclide on land and water bodies. Sediments accumulated since the early 1950s often have measurable amounts of cesium-137, while older materials are free of this material. Sedimentation rates can be inferred by locating the depth at which this material is first detected. This method has been used in salt marshes to date sedimentary deposits (Delaune et al. 1978). Studies at Houghton Lake MI have shown that this method is valuable for the determination of accretion rates of solids. Lead-210 also may be used in a similar manner. In contrast to cesium-137, lead-210 is present in the air as a result of natural processes and is deposited in soils and sediments at a nearly constant, long-term rate. The activity of this radionuclide decreases with sediment depth as a result of radioactive decay during burial. The activity of lead-210 can be measured for about 100 years. In undisturbed sediments, the activity decreases exponentially with depth at a rate that is dependent on the sedimentation rate. This technique has been used by Robbins (1978).

A third radioactive tracer method is the commonly used radiocarbon dating technique for organic materials. This technique may be used to estimate the approximate age of a wetland containing organic deposits. It is not useful for processes less than a few hundred years old, but would provide information on the overall age of a particular wetland. This type of measurement would be valuable for identification of the history of the wetland.

The processes of chemical leaching should be studied at each potential wetland site in order to ascertain the long-term effects on the wetland. Information on processes of this nature can be obtained in the laboratory by accelerating the process of exposure to those chemicals that may cause soil degradation. Such experiments would include the testing of the soil substrate at each site, and possibly at several locations, by two laboratory procedures: (1) exposure of a known soil sample to a fixed amount of the constituent chemical of interest, followed by an observation of the effect on soil quantity and properties; and (2) measurement of the penetration of the chemical by diffusion into the soil substrate.

2.7.2 Sediment Processes

Sediments are defined as those solid materials that are capable of movement within the wetland waters. This distinguishes them from soils which would not normally be capable of movement. Sediments enter the wetland through incoming waters, precipitation, litter fall, and dusting, and may leave by similar mechanisms. Sediments are generated within the wetland by processes of physical/chemical breakdown of plant materials and decomposition of algae and other plant litter. These materials are mobile and may transfer significant amounts of nitrogen, phosphorus, and other chemical substances. The amount of sediment that occur in the incoming streams, the outgoing streams, and the wetland water storage pool should be determined in order to assess the effects of applied wastewater.

Known volumes of water can be collected by filtration to determine the total amount of suspended solids in any sample and to determine the fraction of that amount that is volatile (organic). Sampling should be conducted at the same stations that are used for the hydrological studies.

It also would be valuable to collect suspendable material by adding water to a sample, agitating, and collecting the resulting sediment-laden water. The purpose of this procedure would be to obtain a sample of the suspendable materials. This material can be transported by increased flows that could occur when wastewater is applied to a wetland.

Sediment traps should also be used to determine the amount of sediments accumulating over a specified time period. The traps would consist of shielded containers placed with their tops just above ground level. All solid material would be removed, dried, and weighed at designated sampling intervals. This procedure would permit estimation of the rates of sediment deposition at individual stations.

2.7.3 Implementation of Methodologies

Sedimentation processes lead to reduction of the suspended solids present applied in wastewater. Because changes in sedimentation can greatly affect the structure and function of wetlands, it is recommended that measurements of suspended solids be made at all study sites. It is estimated that one person-day per site would be required to obtain samples for the appropriate laboratory tests. Carbon dating of the bottom soil horizon from at least one location at each site is recommended. The use of the cesium-137 technique to determine baseline sedimentation rates also should be done at at least one location at each site. Each major soil type in the wetland should be tested for the chemical leaching in order to determine potential effects of high pH waters that would exist at most municipal facilities. Similar tests should be run at sites with discharges that have a low pH.

Carbon dating of the bottom horizon can be done commercially by Krueger Enterprises, located in Cambridge MA. The chemical leaching experiments would require approximately one person-week of laboratory work per wetland. The cesium-137 experiments and lead-210 work would require about two person-weeks per wetland.

The placing of soil staff gauges would require approximately one person-day per set of staff gauges installed. This field work could be accomplished in conjunction with other parts of the study. The sediment traps should be placed at approximately the same locations as the staff gauges.

Both the field reading of instruments and the collection of samples should be done simultaneously with the hydrology fieldwork. Grab samples of suspended solids should be taken at inflow and outflow points at the same time as the flows at those locations are measured. Measurements of suspendable solids could be taken less frequently. The comparative staff gauges need to be only two or three times per year.

The process of windborne solids entering the wetland probably is not considered to be important enough to measure. It is also assumed that methods for assaying algal productivity will provide the information necessary on the generation of algal detritus (Section 2.8.3). The total interpretation and analysis of the information from a given wetland site for sediments and soils would require an estimated one person-week per wetland per year.

2.8 METHODOLOGIES FOR INVESTIGATION OF EFFECTS ON WETLAND STRUCTURE AND FUNCTION - BIOLOGICAL COMPONENTS

The major categories of organisms that potentially could be affected by wastewater discharges in a wetland ecosystem include plants, invertebrate animals, and vertebrate animals. Because of the multitude of types of organisms that inhabit wetlands, the lack of data on the population dynamics, life histories, and roles of many species, and the temporal and financial restrictions of the full-scale study, the methodologies developed to identify and assess impacts on biota consist primarily of techniques to characterize the biological communities at each study site and to determine adverse effects on these communities by looking for evidence of changes in structure, function, and distribution of these communities at the site. Specific detailed methodologies cannot be developed until the actual study sites have been selected. At that time, adjustments can be made to tailor the methodologies to each type of wetland to be investigated and to each individual site. It is intended that this process will begin with the initiation of the literature review for each disciplinary area or issue category, and will be refined on the basis of the information obtained during the detailed site surveys.

Determination of the impacts of wastewater discharge will require an interdisciplinary approach, because the physical, chemical, and biological components of wetlands are interconnected. Therefore, the results of studies performed by researchers from different disciplines would be used to interpret the results of the vegetation studies. For example, the results of the hydrological, soil, and water chemistry studies would be used to help interpret data on plant growth and distribution, because levels of contaminants and nutrients in soil and water, as well as changes in water level, all are known to affect wetland vegetation.

The relationship of the physical and chemical studies to the biological investigations are shown in Figure 2.8-1. The biological investigations are presented in this section according to the major groups of organisms present in wetland ecosystems and their approximate place in the wetland food chain sequence:

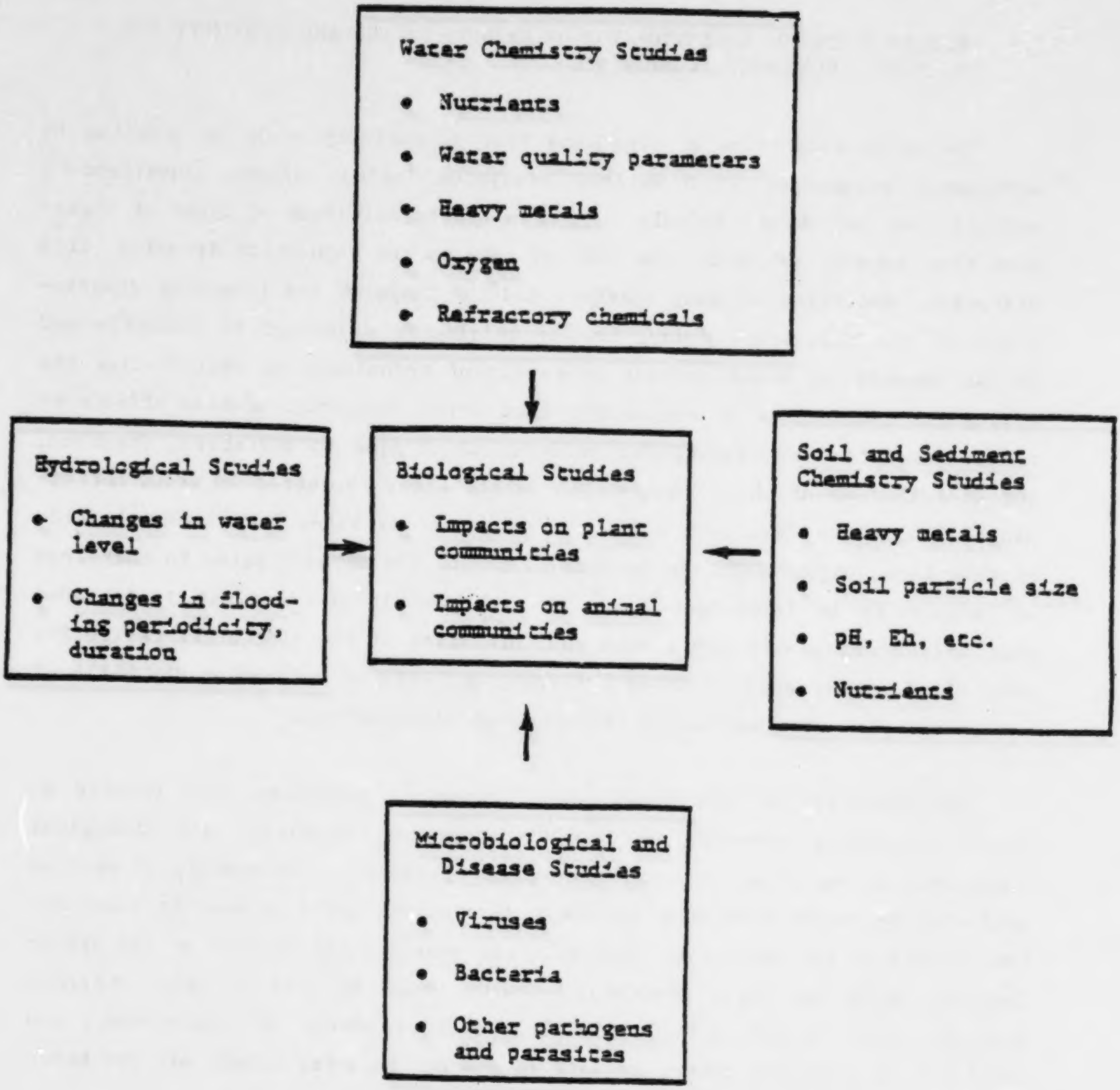
Water Chemistry Studies
• Nutrients
• Water quality parameters
• Heavy metals
• Oxygen
• Refractory chemicals
Hydrological Studies
• Changes in water level
• Changes in flooding periodicity, duration
Biological Studies
• Impacts on plant communities
• Impacts on animal communities
Soil and Sediment Chemistry Studies
• Heavy metals
• Soil particle size
• pH, Eh, etc.
• Nutrients
Microbiological and Disease Studies
• Viruses
• Bacteria
• Other pathogens and parasites

Figure 2.8-1. Relationship of other research investigation to biological studies.

- Plants (the primary producers);
- Invertebrates (limited to benthic macroinvertebrates and insects, the typical indicators of pollution and major sources of food for vertebrates);
- Fish, and
- Wildlife (amphibians, reptiles, birds, and mammals).

Methods to address the issue or concern identified are discussed. All researchers attempted to include the most up-to-date techniques and information known for the study of each group of organisms, to identify the key parameters or types of organisms to be investigated, and to develop methodologies as consistent as possible with those used by researchers currently studying wetland treatment/discharge sites in USEPA Region V and elsewhere.

2.8.1 Plant Species Composition

A research program designed to determine the impacts of treated wastewater effluent on the species composition of wetland plant communities would include the following components:

I. Literature review
  A. Obtain information on types of wetlands receiving discharge to be studied and on individual sites.
    1. Obtain data on any previous studies on particular type of wetland or on specific wetland receiving discharge (if available).
      a. Data should include list of dominant species, list of subdominant species, and aerial photographs.
      b. Data sources: colleges, universities, government libraries (Federal, state); other sources such as state or Federal agency personnel working in the study area.

II. Prepare detailed plan of field study
  A. Review background literature.
  B. Determine approach to be used in fieldwork for particular sites selected.
    1. Emergent vegetation: measure species composition in experimental plots as function of increasing distance from discharge and over period of time (four seasons).
      a. Determine size of plot to be used.
      b. Determine number of plots to be used.

c. Determine location of plots relative to cover types.
d. Determine sampling schedule.
e. Decide on appropriate method to estimate species composition; available methods:
    1) Knighton (1980): ground level photographs plus ground proofing; MAP-O-GRAPH technique.
    2) Biomass harvest technique (i.e. species harvested).
    3) Line-intercept method (Kadlec et al. 1978).
    4) Plot method (Ewel 1976, Fritz and Helle 1978b).
f. Determine marsh-upland boundary based on vegetation type; available methods:
    1) Five percent method, joint occurence method (Harvey et al. 1978 in Eilers et al. 1981); multiple occurence method (Fenkel et al 1978 in Eilers et al. 1981): established lists of wetland and upland indicator species.
    2) Cluster analysis (Boesch 1977 in Eilers et al. 1981), similarity ISJ and ISE indices utilizing Jaccard's method or Ellenburg's variation on the Jaccard's index (Mueller-Dombois and Ellenburg, 1974 in Eilers et al. 1981): methods assume no preclassification of plant indicator species.

2. Submergent vegetation: measure species composition, species diversity, and biomass of replicate quantitative samples randomly collected with Ponar sampler or coring device as a function of increasing distance from discharge.
3. Forested wetlands
    a. Obtain aerial photographs of control and impacted areas.
    b. Prepare vegetation maps of each site; ground verify maps.
    c. Stratify each site into component vegetation communities; indicate on map.
    d. Locate random sites within each vegetation type (strata) for further sampling.
    e. Conduct field study, using one or more of the following alternative approaches:
        1) Measure species diversity, species composition, biomass in randomly placed replicate plots in each stratum (size of plots and number of replicates also would have to be determined); compare same parameters in control and impacted wetlands, using similarity coefficient.
        2) Use gradient method of Whittaker (1967) to assess changes in species composition along discharge gradient.
        3) Investigate possible use of forest dynamics modeling approach: Phillips (1969) SWAMP model of impacts of hydrologic changes in floodplain forest dynamics or Franz and Bazzaz (1977) study of bottomland forest species composition as function of flood stage probabilities.
        4) Use approaches described by Ewel (1976), and Ewel and Odum (1978, 1979), Kangas (1976), or Myers and Shelton (1980) for investigation of species composition, biomass, structural features, etc... (because of the

level of detail required to indicate the differences between these methods, they are not described in this report).

4. Data interpretation: use classic vegetation description methods to give estimates of species frequency, percent cover, importance, etc. For long-term study, use similarity coefficient over time.

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2.8.2 Areal Distribution

Several investigators also have used remote sensing techniques to delineate wetland vegetation boundaries. Gilbert et al. (1980) used remote sensing techniques to map wetlands in the sandhills of Nebraska. The approach used was to compare the accuracy of LANDSAT wetland maps with the accuracy of color infrared photographs over a 120-square-mile area. Gilbert et al. (1980) made a similar comparison for a smaller wetland. LANDSAT imagery has been used by several workers including LaPerriere and Morrow (1978), Rundquist and Turner (1980), Nye and Brooks (1979), Montanari and Wilen (1978), and Bartlett and Klemas (1980). LANDSAT imagery is now available at a resolution of 0.25 acres. The State of South Carolina has also developed an inexpensive, practical system for wetland mapping using a newly developed infrared film (Kodak aerochrome #2443 - Estar base) that effectively distinguishes between different types of plant communities.

I. Literature review
  - A. Obtain any available aerial photographs of wetland from appropriate state and Federal agencies or other sources.
  - B. If suitable photos are not available, gather information needed to prepare for field study.

II. Prepare detailed plan of study
  - A. If existing photographs are available and usable, prepare maps of wetland showing changes in wetland vegetation over time.
    1. When submitting requests, the following information needs to be included:

- Coordinates of wetland
- Type of coverage (overlapping coverage is needed)
- Time constraints (what dates, how far back in time)
- Type of photographs (black and white, color, IR)
- Scale

For large wetlands, LANDSAT imagery may be useful, but it would not be suitable for small areas because the current technology limits the resolution to about a 4-acre area. ERDAS, Inc. of Atlanta GA, currently is developing a system that will be capable of analyzing at 0.25-acre resolution, so that LANDSAT data eventually could be used for almost every wetland of a few acres or more. However, there is no substitute for detailed (1"=200' or 1"=400') on-site aerial photographs made specifically for the site to be studied, because of the greater detail provided.

2. Maps must be prepared from overlapping series (at least 30%) at a scale sufficient to provide needed detail for the size of the wetland involved. Typically, a scale of 1"=400' or less is suitable. The maps should be prepared using a stereoscope.
3. Maps must be ground-checked in the field during the summer in order to verify the patterns observed.
4. Based on the maps prepared, calculate the area of each vegetation type, using a polar planimeter. Determine the rate of change of area of different vegetative types over time.

B. Take aerial photographs (if not available) and develop vegetation maps

1. The purpose of this step is not to show changes in areal distribution, but to complete the required biomass and species composition studies.
2. Recommended method:
    a. Determine approximate size of wetland to be mapped.
    b. Based on the size of the wetland, select the flight height to produce adequate scale (1"=200' or 1"=400') photos.
    c. Take photographs:
        1) Shoot from correct altitude using Kodak aerochrome film (infrared film type 2443 Estar base); also shoot

series with color print film (Kodacolor ASA 100), using polarizing filter.

2) All shots should be taken with a special aerial photography camera or nonwide angle lens to avoid edge and scale distortion.

3) Shoot to obtain overlapping sequence by using motor-driven camera.

4) Photos must be taken by shooting vertically. A camera pod that attaches to the wing or wheel struts of any small plane has been developed by Dr. Joseph Rostron and Dr. William A. Shair of Clemson University, and would be ideal for such a study. Techniques for low-level stereo photograpy using 35-mm cameras also have been developed by University of Minnesota researchers.

5) Overflights should be made during spring, summer and autumn to determine extents of different plant communities.

6) Photos should be used to prepare vegetation maps by processing with stereoscopic techniques, using a zoom transfer scope. Areas of vegetation communities can be calculated with a polar or electronic planimeter. Images should be transferred to Mylar overlays and maps prepared showing extent of vegetation zones.

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2.8.3 Plant Biomass, Growth, and Production

The objectives of this study would be to demonstrate the degree of uptake of nutrients by plants as a function of distance from the discharge and to test for potential differences in biomass, growth, and production that could be caused by increased nutrient levels. The following outline summarizes a research approach (and references to methods) that could be used to address these questions:

I. Conduct literature review for specific wetland; formulate hypothesis

  A. Collect background data

  B. Review data

  C. Develop hypothesis for specific wetland

II. Plan study and develop field methodologies

  A. Emergent vegetation

    1. Tissue nutrient levels

      a. Stratify habitats in receiving wetland using maps developed from aerial photography.

      b. Design random sampling pattern within each vegetation type.

      c. From within each strata, collect replicate monthly samples of aboveground and belowground biomass. Subsample biomass samples for tissue analysis. Obtain dry weights of biomass samples for growth and production estimates. Harvest aboveground biomass using a quadrat sized according to the methods of Greig-Smith (1964) (a larger quadrat may be needed, depending on the type of vegetation). Harvest root biomass with a 10-cm plastic core to a depth of 20 cm or where roots end (at least three replicate samples needed at each station). As check on accuracy of 10 cm core, also take smaller number of 0.5 m^2 cores at start of study. Compare data with 10 cm core results. Separate material in laboratory into different species, and into standing dead, standing live, and litter components. For all tissues, determine ash content, express data in grams of carbon per square meter of surface area and as dry weight/m^2. Analyze subsamples of each component for tissue nutrient levels, using one of the following techniques, and compare to National Bureau of Standards data to confirm:

        1) Acid-digestion technique (Van Lierop 1976); colorimetry (Tilton and Kadlec 1979).

        2) Acid-digestion technique (Wikum and Ondrus 1980); vanadomolybdate colorimetric method (American Public Health Association 1976).

        3) X-ray fluorescence (Mudroch and Mudroch in press).

    d. Analyze for total P, total N, and other desired materials.

2. Biomass and production of emergent vegetation
    a. Sample above and below ground biomass monthly.
    b. Use at least two methods to determine production, in order to compare accuracy.
        1) Harvest method of Smalley (1958).
        2) Turner "end of season" method (Turner 1976).
        3) Predictive periodic model (PPM) of Hackney and Hackney (1978).
        4) Net annual primary production method (Stout et al. 1980).
        5) Monospecific or mixed species stands net annual primary production methods (USEPA 1980).

3. Statistical analysis
    a. Test data for homogeneity of variances and normality of distribution; transform and retest if necessary.
    b. If transformation is effective, perform appropriate parametric analyses. If not effective, try different transformation or employ nonparametric procedures. Develop and test "a priori" hypothesis where possible.
    c. Types of statistical analysis:
        1) Descriptive statistics for nutrient levels: mean, range, standard deviation for all stations and dates.
        2) Initial testing: ANOVA for differences between stations and/or dates; followed by multiple comparison procedure (such as the SNK, or Student-Newman-Keuls Test) (Sokal and Rohlf 1969) to determine which means are different among stations or dates.
        3) Test for correlations between biomass and nutrient levels, using correlation coefficient applied to pooled data over the period of the year or for each sample date (once a month). Use coefficient of determination (r^2) to determine statistical validity of correlation regression.

B. Submerged vegetation (macrophytes)

1. Determine boundaries of aquatic habitat affected by discharge.
2. Conduct preliminary survey to determine if submerged vegetation exists in study area.
3. If vegetation is found, plan study:
    a. Conduct monthly sampling of benthic vegetation of stations along gradient away from discharge, or above and below discharge if possible.
    b. Sample from a boat along transects from shore. Sample at regular, increasing-depth intervals in transects perpendicular to shore. Use quantitative Ponar sampler.
    c. Estimate biomass of component species; present data in grams of carbon and dry weight per square meter; analyze tissues for nutrients as above.
    d. At each station, measure water quality parameters (including nutrients, light intensity, water temperature, and hydrological parameters) monthly over a period of at least one year.
    e. Conduct statistical tests of difference in biomass for each species as a function of distance from the discharge. Use singleway ANOVA as first test for differences. If initial differences are found between stations, test further using SNK multiple comparison test. Correlate biomass to nutrient levels. Employ turbidity tolerance index to determine possible turbidity impacts on biomass (Davis and Brinson 1980).

C. Phytoplankton, Epibenthic Algae, and Periphyton

1. Phytoplankton: determine the eutrophication potential of wetland waters that receive treated effluent, using algal bioassay procedure.
    a. Use USEPA algal assay procedure: bottle test (USEPA 1971).
    b. Conduct test on samples collected as a function of increasing distance from discharge or above and below discharge.

        c. Results of test (which define the ability of the water to stimulate algal growth) will provide estimate of effectiveness of tertiary treatment by wetland; i.e., if nutrient removal is truly effective. Also, test results will indicate the potential for algal blooms.

2. Water column/benthic plant metabolism: measure community metabolism with diurnal oxygen curve method (Odum 1969). Compare metabolism over 24 hour period either on gradient in discharge or in reference area.
3. Epibenthic algae: monitor potential blooms of nuisance algae on marsh surface due to effluent.
    a. Use qualitative observations of nuisance growths only.
    b. If growths are observed, sampling of biomass should be conducted. Sample biomass of surface growing algae using 10 to 20 cm core sampler (one core can be taken from each emergent biomass quadrat before harvesting to save time). Qualitatively identify plant species present in each core, determine ash-free dry weight and biomass/m^2; estimate mean, standard deviation, and range of biomass; determine how biomass changes as function of distance from discharge; analyze statistically; determine N and P content of tissues.
4. Periphyton: monitor periphyton populations by using glass slide method and sampling of natural periphyton populations in marsh using methods described in Weber (1973). Determine cell densities, species diversity indices, equatibility, number of species, and relative percentage composition of major groups in replicate slides at each station. Compare reference area to affected area or periphyton along gradient of discharge.

D. Forested wetlands
1. Study possible changes in wetland forest vegetation biomass, growth, and production due to possible impacts of effluent (hydrological, chemical impacts).
    a. Delimit or define study area boundaries - area affected by the discharge.

1) Use photographs of site, plus ground verification to prepare vegetation map of site.

2) Delineate vegetation zones or types on vegetation map; superimpose random dot grid on map; choose random sites within each vegetation zone (strata).

b. Measure changes in growth and production of dominant species as a function of increasing distance from discharge.

1) Wikum and Ondrus (1980): measure current year's growth of dominants at randomly selected locations in each vegetation stratum as function of increasing distance, or in control and impacted areas.

2) Brown (1982): measure trunk diameter height and species in randomly placed 10m x 10m plots within stratified zones of wetland; determine aboveground biomass using least-squares regressions of wood, leaf, and total biomass against dbh (Whittaker and Woodwell 1968). Brown (1981) also includes methods for studying chlorophyll levels, metabolism, transpiration, plant-surface area relationship, and litter fall of forested swamp.

3) Kadlec et al. (1978): measure shoot elongation of replicate plants as function of increasing distance from discharge.

4) Burnett (1976): extract cores from canopy trees; analyze tree ring growth using ocular micrometer and stereomicroscope to measure annual tree ring increment. Diameter at breast height also should be measured at time core is taken from tree for later determination of basal area increment per year; determine rate of growth 10-15 years before and 10-15 years after addition of effluent and compare statistically with similar data for control area.

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2.8.4 Detrital Cycling

The objectives of this portion of the study would be to determine the impact of wastewater application on rates of decomposition of detritus of dominant wetland plant species. Additional objectives would be to determine the impact of wastewater application on levels of nutrients in detritus of dominant wetland plants and to determine the impacts of wastewater on detrital production rates. The following outline summarizes the major steps required to conduct such a study and references to methods dscribed.

I. Conduct literature review for particular wetland type
  A. Collect background data
  B. Review data
  C. Develop hypothesis for specific wetland

II. Plan study and develop methodologies
  A. Use similar methods for all wetlands
  B. Planning
    1. Conduct preliminary site survey.
    2. Determine dominant species of plants (from other parts of study).
    3. Make needed number of litter bags from plastic window screen.
  C. Field work
    1. Place 10 grams of fresh leaf material collected at the end of the growing season into each of several replicate litter bags at each station. Place replicates at stations located at increasing distance from discharge, or in alternate design, in control and impacted areas. Place one set of bags directly on marsh surface (water level) attached to plastic stake. Place a second set suspended above the water level in order to provide an estimate of rate of decomposition of standing dead compartment. Use enough bags to enable retrieval of triplicate samples from each station at 1 week, 2 weeks, 4 weeks, and monthly thereafter for 1 year (total time) (Chamie 1976).

D. Analysis

1. Return bags to lab; clean, dry, grind, and weigh contents. Analyze for Kjeldahl N and total P using microKjeldahl technique (American Society of Agronomy, Inc. 1965) and tube digestion technique (Sommers and Nelson 1972), respectively.
2. Illustrate data on graphs showing mean percent of original weight left in triplicate samples for each sampling date. Illustrate mean and standard deviation on same graph. Calculate decomposition rate coefficient (discussed in Chamie 1976).
3. Analyze data statistically using ANOVA after testing data for homogeneity of variances and normality. Use appropriate transformations as required. Use ANOVA to test for differences due to wastewater application in rate of decay and levels of N and P. Also test for possible correlations between moisture level and decay rates since previous studies have shown good relationships (Sanville 1981).

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A proposed sampling schedule for all of the plant studies outlined in Sections 2.8.1 through 2.8.4 is provided in Table 2.8-1.

2.8.5 Trace Metals and Other Trace Elements

The objectives of this study would be to: (1) determine levels of selected trace metals and other trace elements in vegetation in the receiving wetland; (2) determine the significance of observed levels of trace elements, i.e., with respect to potential impacts on wetland plants; and (3) determine the possible role wetland vegetation plays in removal of trace metals and other trace elements, as compared with sediments or other components of the system.

I. Conduct literature review for particular wetland types
   - A. Collect background data
   - B. Review data
   - C. Develop specific hypothesis

II. Plan study and develop methodologies

A. Use similar methods for all wetlands

B. Planning

1. Analyze quarterly replicate biomass samples (all components) of emergent vegetation, submergent vegetation, and bottomland trees (foliar growth samples) for levels of trace elements (6 replicates per stratum). This will provide information on all plant parts (both living and dead).

2. Compare trace element content of reference site and area receiving wastewater or as a function of increasing distance from discharge.

3. Analyze parameters (Ni, Zn, Ca, Cr, Pb, Hg; possible other elements Ca, K, Mg, Fe, Mn, Mg) by using one of two analytical methods:

a. Alternative 1: neutron activation analysis (NAA) using Phoenix Memorial Laboratory at The University of Michigan. Advantages include the ease of analysis, highly precise results, speedy turn-around time. The main disadvantages include the high cost and the fact that two metals of particular interest, copper and lead, cannot be measured with NAA.

b. Alternative 2: acid digestion/atomic adsorption spectroscopy technique (US Army Corps of Engineers 1978). The main disadvantage of this technique is that all elements cannot be analyzed with one technique. However, the method is less expensive than NAA.

c. Alternative 3: inductively coupled plasma resonance technique.

4. Data Analysis

a. Analyze data statistically to test for differences as function of distance from discharge or between similar habitats (species) in control versus impacted areas. Use ANOVA and multiple comparison techniques; present data using descriptive statistics: include mean, standard deviation, range.

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Table 2.8-1. Proposed sampling schedule for investigation of effects on plant communities.

Parameters to be Sampled/Technique	Bi-monthly	Monthly	Bi-annually	Annually	Other
Emergent vegetation					
Species composition	X (May through late September)				
Biomass, growth, and production		X			
Heavy metals analysis					X (quarterly samples)
Submerged vegetation					
Species composition				X (August or early September)	
Biomass, growth, and production				X (August or early September)	
Heavy metals analysis					X (quarterly samples)
Forested wetland					
Species composition				X (August or early September)	
Biomass, growth, and production	X (from early May to late September)				
Heavy metals analysis					X (quarterly samples)
Phytoplankton/epibenthic algae					
Biomass, growth, and production					
Bioassay				X (August)	
Epibenthic algae		X (if nuisance growth occurs)			
Heavy metals analysis					X (quarterly samples)
Detrital cycling		X			
Mapping of areal distribution of component species					X (one overflight in spring, summer, and early autumn)

The proposed sampling schedule for the investigation of effects on plant communities was presented in Table 2.8-1.

2.8.6 Macroinvertebrate Populations

The objectives of this portion of the study would be to: (1) determine changes in invertebrate population structure caused by added wastewater; (2) determine the potential for food chain magnification of trace metals by aquatic invertebrates; and (3) determine the potential for disease transmission by invertebrates to other portions of the food web, including man. A research program designed to meet these objectives (including references to methods) is summarized in the following outline (a proposed sampling schedule is provided in Table 2.8-2):

I. Literature review
  A. Collect literature on study area, including general features (chemical, physical, geological, biological).
  B. Review literature on study area and on freshwater invertebrates (such as Buikema and Benfield 1980) to assist in selection of indicator species and of the stages of life cycles of those species to be examined for estimation of toxic effects.
  C. Formulate specific hypotheses.

II. Changes in invertebrate population structure
  A. Planning
    1. Use same areas that vegetation study employs for stratified random sampling; use same approach for location of samples.
    2. Sample either as a function of distance from the discharge or in similar control and impacted areas.
  B. Field work
    1. Collect quarterly replicate benthic samples at each vegetation station, using one of the following alternative methods:
      a. For deeper areas, samples should be collected with a Ponar grab device.
      b. For areas shallower than 1.0 meter, a coring device should be employed such as that described by Merrit and Cummins (1978) and used by Kaminski and Prince (1981) to study the

Table 2.8-2. Proposed sampling schedule for investigation of effects on macroinvertebrates and insect communities.

Parameters to be Sampled/Techniques	Frequency of Sampling	
	Weekly	Quarterly
Macroinvertebrates		
Population structure and abundance		
Ponar grab device (deep areas)		X
Coring device (shallow areas)		X
Insects		
Population structure and abundance		
Relative sampling	X (May to September)	
Absolute sampling	X (May to September)	
Indicator species	X (May to September)	

relationships between ducks and aquatic invertebrates at the Delta Marsh in Manitoba, Canada. Swanson (1978a, 1978b) also described a coring device for use in shallow wetlands that should be considered. The advantage of this device is that it is calibrated for depth and volume, which permits more accurate quantitative measurements.

   c. Voigts (1976) sampled free-swimming invertebrates associated with wetland vegetation using a 0.1 m^2 dip net pulled vertically through the water column. This method provides a quantitative estimate of the density of invertebrates per cubic meter of water. Voigts (1976) also sampled randomly selected locations along permanent transects to obtain estimates of the mean number of invertebrates and an estimate of variability between samples.

2. Because abundance and diversity of aquatic invertebrates are known to be correlated with the presence of aquatic plants (Wetzel 1978; Voigts 1976), it is necessary to sample the plants also.

   a. Small coring devices such as that described by Swanson (1978a, 1978b) cannot be used to adequately sample aquatic plants. Aquatic plants must be harvested with a larger-mouth device, such as that described by Wood (1975). Krull (1970) used an Eckman dredge to sample benthic plants and invertebrates simultaneously. The dredge is equipped with an extra-powerful spring to ensure that the plant material does not cause the mouth of the grab to remain open. For areas of heavy plant litter that cannot be sampled by any of the above methods, Kaminski and Prince (1981) recommended use a steel frame covered with nylon netting designed by Gerking (1957).

   b. Sample three replicates at each station. Sort and weigh vegetation samples.

   c. Process samples in laboratory, to obtain following types of data:

      1) Mean invertebrate density and biomass at each station sampled; do same for vegetation samples.

2) Mean density and biomass for each taxon at each station.

3) Mean, standard deviation, range and coefficient of variation for each station and taxon.

4) Use four different estimates of diversity for each station: Shannon-Weaver ($\bar{H}$); Simpson's index of diversity (Simpson 1949); Simpson's index of dominance; biotic index for tolerance of taxa to pollution using method of Chutler (1972).

5) Rank stations with respect to diversity, dominance, biotic index values; compare with physical and chemical data.

6) Evaluate effectiveness of sampling or compare impacted versus reference areas using rarefaction technique of Sanders (1968).

7) Compare stations with each other using coefficient of community (Whittaker and Fairbanks 1958, Johnson and Brinkhurst 1971, Fay et al. 1978), and the Percent Similarity of Community (Whittaker and Fairbanks 1958).

8) Classify organisms according to trophic status according to Merrit and Cummins (1978). Also determine tolerance of organisms to organic decomposable wastes based on information provided in Weber (1973).

III. Potential for transfer of trace metals or chlorinated hydrocarbons through the food chain

A. Measure trace metal content of selected invertebrate species in samples by neutron activation analysis (or atomic adsorption) of subsampled dominant organisms from control and impacted areas or as function of increasing distance from discharge.

1. Relate to levels in water and sediment as determined in other parts of study.
2. Relate to literature.
3. Relate to levels observed in higher food chain organisms (fish) sampled in other parts of the study.

B. Evaluate impact of chlorine or chlorinated hydrocarbons on invertebrates

1. Can only be done indirectly via measurements of population changes as per above.
2. Interpretation will be hypothetical and qualitative, based on correlation of levels of chlorine and/or chlorinated hydrocarbons in relation to other contaminants and factors (oxygen levels, sediment, etc.).
3. Could consider use of standard bioassay technique or other laboratory type tests to determine chlorine toxicity.
4. Determine bio-magnification level if data are available to do this.

IV. Potential role of invertebrates in transmitting disease
(Refer to Section 2.8.7 for methods)

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2.8.7 Insect Populations

Witter and Croson (1976) provided a review of methods used to sample insects in wetlands, and compared the relative effectiveness of each method. Two basic types of methodologies can be employed: relative and absolute. Relative methods, such as malaise traps, pitfall traps, and light traps, are easier and less expensive to employ, and comparisons between areas are possible using these methods. However, the size of the catch obtained by relative sampling methods is affected by: (1) changes in population size; (2) changes in insect activity; (3) changes in insect developmental stage; (4) trap efficiency; and (5) variable response to traps by insects of different orders. Absolute sampling methods, such as emergence traps, extraction of soil cores or blocks, and clipping or vacuum suction of vegetation in a known area, provide for a quantitative estimate of abundance, but are very costly to employ because of the labor involved in collection and analysis.

Southwood (1981) summarized information concerning various types of "suction" traps that also can be used effectively to sample insects from the air. These basically include the exposed cone, enclosed cone, and rotary types of traps. Southwood (1981) provided detailed information on factors affecting suction trap efficiencies (including density of insects, wind speeds, and information on periodicity) and how to account for variations produced by these variables. He also included a discussion of how to calculate areal densities and total areal populations from catch data. This reference should be consulted prior to designing the study, because it is the most up-to-date summary of methods and approaches of studying insect populations.

An additional possible approach would be to use the methods described by Smith (1969), who studied the mosquitoes inhabiting sewage treatment oxidation ponds in Missouri. His approach was to estimate egg densities, larval abundance, and adult abundance. Egg density was estimated quantitatively by counting eggs laid on artificial rafts placed in the field. The rafts, called "artificial oviposition blocks", were made from polystyrene plastic of known dimensions. Larvae were sampled with a long-handled dip net in the field, and an estimate of the numbers per dip was made. Adults were sampled using the standard New Jersey light trap and/or the USPIISCDC light trap. These methods could be used to sample mosquitoes in wetlands affected by wastewater application, and comparisons could be made to nearby "unaffected" areas.

Witter and Croson (1976) recommended a specific approach to studies of insects in freshwater wetlands that takes into consideraton the factors discussed above. Their approach was to employ indicator species as the basis of studying the particular wetland and to use this method as a means of predicting the impact of wastewater application on resident insect populations. The advantages of this approach are that it is more cost-effective, since fewer numbers of insects must be collected and processed, and also that it specifically addresses the practical issues associated with wastewater application. The disadvantages include the lack of understanding of natural fluctuations of insect indicator species populations, which makes it difficult to relate abundance to specific disturbances. Another difficulty is that little is known about the breeding cycles of most indicator species, so that their emergence may be missed during sampling. Despite these difficulties, the indicator species method probably is the most effective one to use for the proposed study. This method is summarized below.

I. Literature review
  A. Review literature on flora and fauna of region, and information on local geology, soils, climate, and water chemistry
  B. Formulate hypothesis

II. Plan study
  A. Based on hypothesis, select indicator species
    1. Criteria for choosing indicator species
      a. Species must be characteristic components of fauna being studied.
      b. Populations of species must be known to change with parameter of interest (e.g., wastewater addition).
      c. Species of medical or economic importance should be selected - especially biting disease vectors.
      d. Species should be ones that can be sampled easily by techniques suitable to the habitat.
      e. Species should be widespread and common.
    2. Potential species for examination of issues.
      a. Disease vector issue - horse flies, mosquitoes, deer flies.
      b. Water quality issues - chironomids; possible others.
  B. Field study
    1. Priority should be given to use of emergence trap, malaise trap and light trap, based on recommendation by Witter and Croson (1976), and the suction traps described by Southwood (1981); alternatively, use methods described by Smith (1969).
    2. Set traps for 24-hour periods each month from May to early September in suitable locations within control and impacted wetlands; perform other sampling during same periods.
    3. Subsample to obtain workable sample size, sort samples, prepare list of species collected.

C. Analysis of data
  a. Choose 10-12 indicator species using above criteria
  b. Interpret results
D. Report preparation

The sampling schedule for investigation of the effects on insect communities was presented in Table 2.8-2.

2.8.8 Fish Communities

Because methodologies specific to wetlands fisheries investigations have not been developed, the methodologies described in this section are those routinely used during fisheries studies. Where their utility in wetlands investigations is limited or marginal, this fact is noted.

The introduction of wastewater into a wetland may cause species shifts due to:

- Changes in either the water level or the frequency and duration of flooding
- Changes in the forage base available to the fish community
- Alteration of spawning success
- Increase in mortality in certain populations
- Increase in occurrence of diseases in fish.

Regardless of which of the above factor or factors may be affecting species composition, a research program similar to the one outlined below should be followed.

I. Background material
  A. Review the scientific literature for information regarding the area in question or similar areas.
  B. Contact individuals knowledgeable about the area: e.g., city, state agency, or Federal agency biologists; university personnel; local fishermen.
  C. Conduct a preliminary inspection of the area.

II. Planning

A. Based on the water regime of the wetland, determine the basic community type or use that can be expected.

B. Based on the expected community type or use, determine the methods that should be considered for collecting fish (Table 2.8-3).

C. Based on the information obtained during the detailed site surveys, determine which of the gear types is appropriate for the wetland in question.

III. Field work

A. Station location - Choose a suitable number of sampling stations, based on the size of the receiving wetland and the volume of effluent. The arrangement of the stations normally will be related to the distance from the discharge. All habitat types should be sampled. A reference station should be established at a location upstream from the discharge point or, less preferably, in an adjacent similar wetland.

B. Sampling frequency - Sampling should be conducted at least seasonally for a minimum of two years. Monthly sampling for a three-year period would be preferable.

C. Use of the sampling gear - Weber (1973), American Public Health Association (1976), and Hocutt (1978) discussed the standard sampling gears, their proper use, and their limitations. A special push net designed for use in wetlands has been described by Herke (1969).

D. Retain voucher specimens for any unusual specimens.

The following institutions are recommended as depositories for specimens:

- University of Minnesota
- Milwaukee Public Museum
- University of Michigan
- Ohio State University
- University of Indiana
- University of Illinois
- Illinois Natural History Survey.

Table 2.8-3. Methods for collection of fish.

Type of Community		
General	**Forage Only**	**Spawning**
Seining	Seining	Seining
Gill netting	Electrofishing	Electrofishing
Hoop/fyke netting	Push nets	Hoop/fyke netting
Electrofishing		Push nets
Push nets		

IV. Data analysis

A. Quantitative

1. Statistical techniques used in fisheries science have been described by Ricker (1975).

2. General statistical procedures are described in standard biostatistic texts such as those authored by Zar (1974) and Sokal and Rolf (1969).

3. Use of diversity indices have been discussed by Weber (1973).

B. Qualitiative

1. Because of the problems associated with gear selectivity, standardization of unit of effort, lack of suitable controls, and the inherent difficulties associated with properly sampling wetlands, quantitative treatment of the data may not be possible. Qualitative parameters to be examined should include percent species composition, community dominants, changes in the number of individuals or species captured, and differences above and below the discharge.

V. Report preparation

2.8.8.1 Changes in Productivity and Biomass

The measurement of biomass alone usually is of little value, because fisheries scientists generally are more interested in the species of fish that are present than in their total weight. However, in conjunction with other data, statistics related to biomass and productivity can be useful. Two basic parameters which could be examined include: (1) total weight and/or numbers (by species or for the fish population as a whole); and (2) growth of individual fish. Parameters related to populations are extremely difficult to determine accurately. Methodologies for determining changes in productivity or biomass are indicated in the following outline:

I. Collect background material (literature review and contacts)

II. Planning

A. Biomass and productivity estimates would be useful only for wetlands that support general fish communities. The fish collection methods identified for general fish communities also would be applicable here.

III. Field work

A. Population-related studies

1. Assess survival and mortality rates from age-class statistics.
2. Determine population statistics, using mark and recapture methods.
3. Determine growth rates for populations, as described by Ricker (1975).

B. Individual statistics - Use length and weight data to determine the condition factor ($K = w \times 10^5/l$), where w = weight in grams and l = length in millimeters (Carlander 1969).

IV. Data analysis

Analysis and interpretation of population statistics and individual parameters is extremely difficult and should not be attempted without a firm understanding of the variables involved. Appropriate references are Ricker (1975) and Carlander (1969).

V. Report preparation

2.8.8.2 Changes in Spawning Success

The conditions necessary for successful spawning often are more rigorous than those necessary to support other portions of the life cycle. Successful reproduction obviously is necessary for general populations to be self-sustaining. For those species that use wetlands primarily as spawning and nursery areas, successful reproduction in any particular wetland is not necessary each year, provided that alternative spawning areas are available. If alternative areas are not available, then successful spawning during at least some years is crucial to the continued well-being of the species in question.

Documenting changes in spawning success in wetlands is difficult for the following reasons:

- Trawling, the method of choice for collecting ichthyoplankton, usually is not possible in wetlands.
- For reasons that are largely unknown, reproductive success shows tremendous natural variability. Thus, cause and effect relationships are difficult to establish.
- It generally is not known how many fish must be recruited into the population each year for the continued success of that population.
- The dynamic nature of wetlands, especially the seasonal changes in water levels, makes it difficult to separate out effects caused by natural factors (e.g., low water, high temperature) from those caused by effluents.

The methodologies to be used in the determination of impacts on spawning success are as follows:

I. Collect background materials (literature review and contacts)

II. Planning

A. Appropriate gear types would include fine mesh (1/16") seines and ichthyoplankton nets (if possible) to collect larvae and electrofishing equipment and hoop or fyke nets to collect spawning adults. Specialized gear such as a buoyant net or a push net may have to be used.

B. Attempt to observe spawning activities: e.g., nest building, adults "running."

III. Field work

A. Station location - Because the primary purpose is to document the successful occurence of spawning, the exact location of stations is not crucial. However, all habitat types (both substrate and vegetational) should be sampled.

B. Sampling frequency - Bi-weekly from early March through the end of July, for at least two (preferably three) consecutive years.

IV. Data analysis
   A. Quantitative - Quantitative analysis would not be possible in most situations
   B. Qualitative - Factors to be considered are:
      1. Collection of "ripe" adults.
      2. Observations of spawning adults (e.g., carp wallowing in the shallows, centrarchids (sunfish) or sticklebacks building nests).
      3. Numbers of larvae collected.

V. Report preparation

2.8.8.3 Determination of Toxicity

Figure 2.8-2 summarizes the methodologies that can be employed to determine fish toxicity and discuss problems in wetlands receiving wastewater. The toxicity of municipal and industrial effluents has been well described (Tsai 1975; Brungs et al. 1978; and Spehar 1980, among others). The constituents of primary concern are residual chlorine, ammonia, detergents, low dissolved oxygen, pH, and heavy metals. The toxicity of effluents is best determined using bioassay methodologies. The bioassays can be performed either by pumping various dilutions of the effluent into aquarium tanks containing test fish or by placing cages of fish at various points in the receiving wetland. Effluent bioassays can be conducted to evaluate short-term (acute) toxicity, long-term (chronic) toxicity, or sublethal effects such as reduced growth, reduced hatching success, or bioaccumulation. Caged fish bioassays generally are used to estimate acute toxicity, but other parameters also can be examined.

The following methodologies should be used to determine if the wastewater effluent possesses significant toxicity:

I. Collect background information
   A. Use the results of the water quality sampling program to identify those constituents that are present in sufficient concentrations to be potentially toxic. Levels for the parameters of concern are given in USEPA (1976).

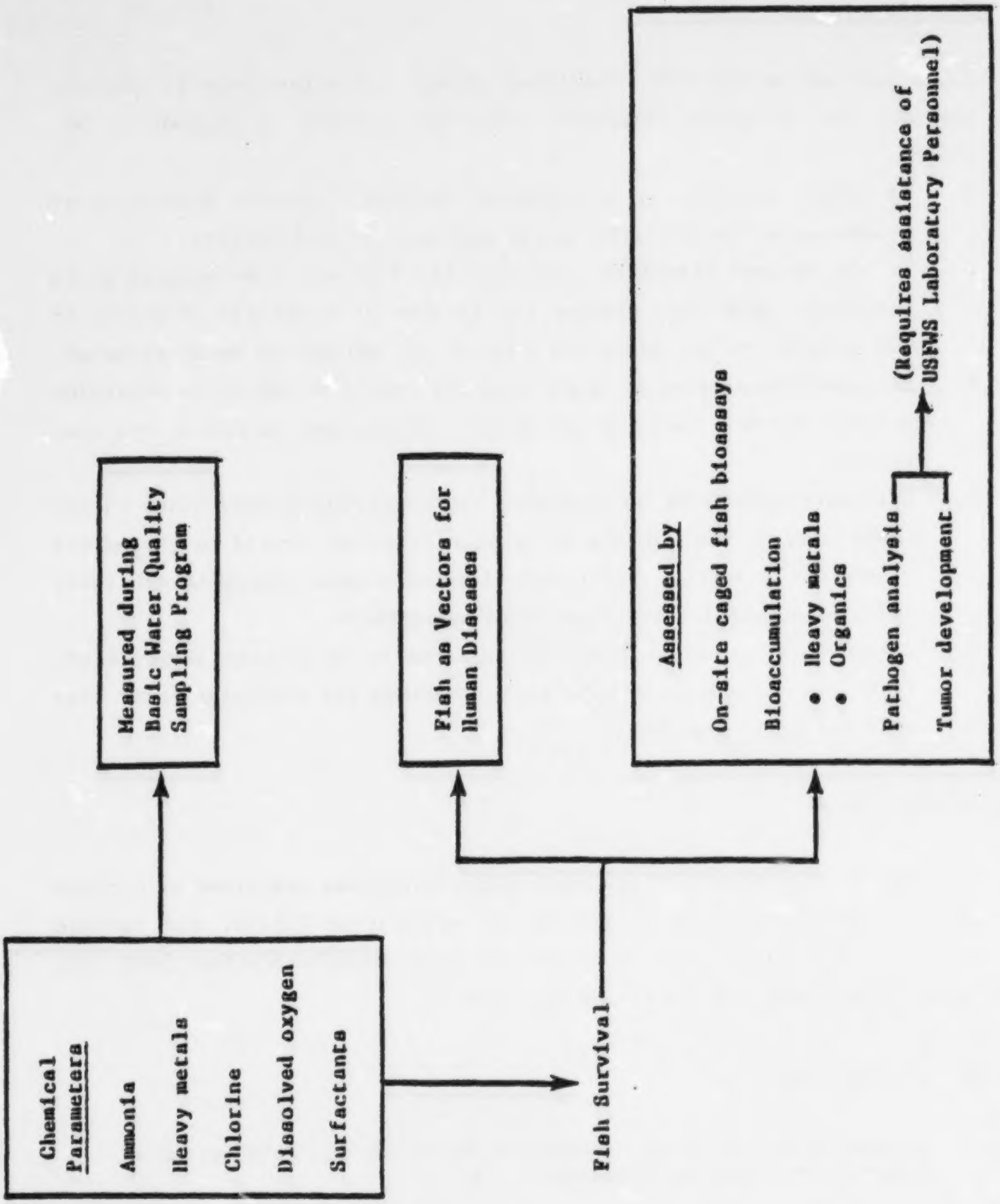
Chemical Parameters
Ammonia
Heavy metals
Chlorine
Dissolved oxygen
Surfactants
Measured during Basic Water Quality Sampling Program
Fish Survival
Fish as Vectors for Human Diseases
Assessed by
On-site caged fish bioassays
Bioaccumulation
• Heavy metals
• Organics
Pathogen analysis
Tumor development
(Requires assistance of USFWS Laboratory Personnel)

Figure 2.8-2. Fish toxicity/disease considerations.

B. Review the toxicity literature available for any constituents identified.

C. Use hydrology information to determine dilution ratios.

D. Inspect the site.

II. Field and laboratory work - Detailed methodologies for properly conducting all the bioassays described below are included in Dickson et al. (1978).

A. If acute toxicity is a potential problem, conduct 96-hour acute bioassays on the effluent, using appropriate test species.

B. If the 96-hour bioassays show that the effluent does possess acute toxicity, caged fish studies can be done at a variety of places in the wetland to determine how much of the wetland is being affected.

C. Effluents possessing no acute toxicity should be tested to determine whether chronic toxicity may occur. Thirty-day exposures are reasonable.

D. Effluents possessing no toxicity, but containing conservative pollutants such as heavy metals or certain organics, should be tested for sub-lethal effects. Thirty-day fathead minnow embryo-larval tests and bioaccumulation tests would be appropriate.

E. Bioaccumulation also should be examined by collecting large, adult fish from various locations in the wetland and analyzing their tissues for toxic residues.

III. Data analysis

Bioassay results should be analyzed using techniques described by Dickson et al. (1978), American Public Health Association (1976), and Sprague (1969, 1970, 1971). The US Food and Drug Admininstration (FDA) has action limits for certain tissue residues.

IV. Report preparation

2.8.8.4 Changes in Incidence of Disease and Potential for Fish Acting as Vectors for Mammalian Diseases

Janssen (1970) and Tsai (1975) have reviewed the relationship between fish diseases and polluted waters and examined the possibility of fish acting as vectors of mammalian diseases. Janssen concluded that most fish-borne human diseases do not cause disease in fish. Tsai (1975) cited several studies that showed a relationship between highly polluted waters and the presence of certain diseases and tumors in fish. However, the nature of this relationship is unclear at present.

Tsai (1975) cited several studies whose authors concluded that fish were not important factors in the transmission of pathogenic bacteria. Although this probably is true for most diseases, Janssen (1970) cited several authors who did establish such links, and suggested that "...fish may be more important vectors of human infectious disease than generally realized."

The methodologies to be used for determination of the incidence of disease in fish and to assess the possibility of fish acting as vectors for human disease are presented in the following outline:

I. Obtain background information
   A. Review appropriate literature (Tsai 1975, Janssen 1970).
   B. Contact researchers active in the field, particularly the USFWS offices in Genoa WI and Leetown WV.

II. Collect fish from several locations in the wetland and send for analysis to a trained fish pathologist at one or more of the following locations:

   A. USFWS - Genoa WI
   B. USFWS - Leetown WV
   C. Department of Health or appropriate state laboratory for the state in question

III. Data analysis

IV. Report preparation

The proposed sampling schedule for the investigation of effects on fish communities is given in Table 2.8-4.

Table 2.8-4. Proposed sampling schedule for investigation of effects on fish communities.

	Frequency of Sampling			
Parameters to be Sampled/Technique	Once	Monthly	Bi-annually	Tri-annually
Diversity indices				
Shannon-Weaver				X (spring, summer, and autumn)
Biomass				
Total numbers		X		
Total weight		X		
Condition factors			X (spring and autumn)	
Species composition				
Dominants		X (March through November)		
Community type		X (March through November)		
Reproductive indicators				
Spawning behavior	X (spring or early summer)			
Collection of "ripe" adults	X (spring or early summer)			
Collection of larvae	X (spring or early summer)			

2.8.9 Methodologies for Investigation of Impacts on Wildlife Communities

The study of animal communities in wetlands is more difficult than the study of plant communities because of: (1) the mobility of the animals; (2) their capability to adjust their activities if weather conditions and other environmental factors are not favorable; and (3) the fact that they may be present only at certain times of the day or seasons of the year. Even if present, an animal may not be observed or captured due to its wariness or because its susceptibility to being trapped varies seasonally. In a study in Florida, Jetter (1974) observed that marked amphibians could not be recaptured in traps, but only by means of dipnets. Traps and other devices used in terrestrial populations may have limited utility in some areas of the wetland due to the presence of deep water. Many more types of methods and devices are needed for the investigation of wildlife communities than for the investigation of plant, invertebrate, or fish communities due to the diversity of the types of organisms and their activity patterns and habitat requirements.

Because of the above factors, wildlife-related studies to be performed on the sites selected for investigation should involve determinations of changes in the type and quality of the habitats present. The information obtained in the baseline study can be used to select the types of research to be performed on wildlife. The baseline data should also be used for comparison with habitat conditions in a nearby reference area.

The majority of the techniques used in studies of wildlife populations are described or referenced in Schemnitz (1980). This material should be reviewed prior to the development of study designs for the wetlands to be investigated. Appropriate journals and reports identified during the literature search should also be examined to obtain recent information on sampling methods and instruments. State and Federal agency biologists familiar with each study area should be contacted to obtain information on the area and the types of species that may be present. A preliminary list of the steps to be taken and the types of methods that could be used in an investigation of baseline conditions and impacts are given in the following outline.

I. Planning

  A. Literature review

    1. Obtain information on type of wetland community at site, previous studies at site.
    2. Review Emlen (1971), States (1978), Schemnitz (1980) and other recent literature to determine most appropriate sampling methods for type of wetland and wetland community.

  B. Develop study design

    1. Determine potential impact sequences and interrelationships and indicator or key species to monitor.
    2. Determine sampling methods, parameters to be sampled, levels of effort, periodicity and duration of sampling.
    3. Determine types and degrees of precision of analyses to be performed on data collected.
    4. Correlate study design with designs for other biological studies at site - vegetation, insects, invertebrates, fish.

  C. Preparation (during overview or baseline survey)

    1. Prepare cover map of vegetation communities, ecotones, structural characteristics of wetland and surrounding areas, including treatment facility if nearby; determine extent of canopy cover and layers of vegetation if forested area.
    2. Prepare field survey forms to be used, obtain or construct necessary equipment.

II. Field Work

  A. Sample treated and reference areas both pre- and post-discharge; sample during all four seasons of the year.

    1. Amphibians

      a. Determine relative abundance and species composition in treated and reference areas.
      b. Use drift fences in combination with pitfall and can traps, cover traps, night-lighting, identification of calling males, searching likely habitat, mark and release techniques, direct observation, recorded calls to stimulate responses.

2. Reptiles
    a. Determine relative abundance and species composition in treated and control areas.
    b. Use similar methods as for amphibians.
    c. Use traps, basking counts for turtles.
    d. Use general habitat searches and night road counts for snakes.
3. Birds
    a. Determine relative abundance, species composition, change in daily and seasonal use patterns.
    b. Use mist-netting, transect studies, direct observation, breeding male calls, nest location.
    c. Band and record sex of birds netted; record number of eggs, fledglings, juveniles of each species; determine fledging success.
    d. Use transect or quadrat methods to conduct census, especially during breeding season; use recorded calls to stimulate bird responses.
4. Mammals
    a. Determine relative abundance and species composition.
    b. Use live-trapping, snap-trapping, direct observation of animals and field signs, scent posts, drift fences.
    c. Note sex, age, etc... of animals captured or observed; collect standard measurements where possible (weight, length, etc., depending on type of animal).

B. Alternate order in which areas are sampled to avoid time bias.

C. Indicate locations of animals observed or captured, nests, etc... on cover map.

D. Check lists of species observed against current Federal and state endangered and threatened species lists; report occurrences to appropriate authorities; note species on Blue List of National Audubon Society or other indicators of declining or rare species.

E. Deposit specimens collected in appropriate depository institution for state; include all relevant information with specimens/

III. Data Analysis

A. Compare species richness, species diversity, and equitability (evenness) for seasonal means and yearly means for treated and control areas, using Shannon-Wiener index of general diversity (H) and equitability index (E), as described in Odum (1971).

B. Use index of similarity (S) or dissimilarity (1-S) as described in Odum (1971) to determine degree of difference between treated and control areas.

IV. Report preparation

2.8.9.1 Changes in Habitat Structure and Components

Much of the information required for analysis of the habitat characteristics can be obtained during the course of the plant, macroinvertebrate, insect, and fish investigations if the study designs in these areas are correlated properly with the needs of the wildlife researchers. However, this information must be organized in certain ways to be useful for the wildlife investigations. The parameters of interest from the vegetation study primarily are as follows:

- Types of plant communities present
  - Structural diversity
  - Species composition
  - Number and extent of ecotones (edges)
- Locations of plant communities
  - Degree of interspersion between vegetation and open-water areas
  - Corridors for wildlife travel to and from the wetland
  - Linear extent of land-water interface or edge.

An ecotone is a transition area between two or more types of plant communities. It contains organisms present in both communities. The number of species and number of individuals of each species are typically greater in the ecotone than in the adjacent communities. This phenomenon is termed the edge effect. It is a particularly important factor in the investigation of avian communities because of the tendency of many species to breed or nest in one type of vegetation and to feed or rest in another. The amount of edge is therefore a major factor in the determination of the carrying capacity of a habitat (the number of individuals or breeding pairs of that species whose life requirements can be met in a particular area).

For the purposes of this study, the classification system developed by Golet and Larson (1974) may be more useful to indicate structural changes in wetlands due to the introduction of wastewater than the recently developed USFWS classification system (Cowardin et al. 1979). This system groups wetlands primarily according to depth of surface water during the growing season, degree of water level fluctuation, and dominant life forms of vegetation. The system of Stewart and Kantrud (1971) would be appropriate for use specifically in glaciated pothole areas. This system is based on differences in permanence and alkalinity, with each class distinguished by 6 different zones of vegetation.

2.8.9.2 Changes in Species Richness and Density

An increase or decrease in the number of species of wildlife that use a wetland receiving applied wastewater as compared to the absence of such a shift in a reference site would be indicative of a significant affect on the wildlife community in the treated area. However, care must be taken to ensure that this change is not due to an external factor unrelated to the presence of wastewater. Any difference in seasonal use of the treated and control areas by wildlife should be noted. For comparison of wildlife use between study sites, the guild concept may prove useful. For example, the species of birds that use different wetlands of the same general type may differ for a variety of reasons, but observations of the number of species that have similar ecological requirements may be used to compare the changes in suitability of the wetlands as habitat for that particular group (i.e., insect-eating songbirds, seed-eating songbirds, or carnivorous wading birds). Use of the guild concept would also permit estimates to be made of the types of changes that have occurred in the wetland food chains.

2.8.9.3 Changes in Abundance of Indicator Species

The quality of the habitat at a wetland treatment site also could be determined by determining the presence or absence of certain indicator species or combinations of such species. Odum (1971) provided the following recommendations on the selection of indicator species:

- The species should have a narrow, rather than a wide, tolerance range for the factor considered to be limiting;
- Large species generally are better indicators than small species because they are present for longer periods of time (have longer life spans);
- The selection should be made on the basis of evidence that the factor in question is limiting; and
- Numerical relationships between species, populations, and whole communities often are more reliable as indicators than single species, especially of pollution, because the group as a whole is more reflective of environmental conditions.

States et al. (1978) suggested that the principal criteria for the selection of animal species for investigation in a baseline study should include:

- Species that are valuable for recreational purposes;
- Species that are threatened or endangered;
- Species that are important to the well-being of either or both of the above groups;
- Species that are critical to the structure and function of the ecosystem; and
- Species that serve as indicators of an important change in the ecosystem.

States et al. (1978) recommended that the design of such studies be based on a thorough knowledge of the ecological requirements of each species in order to determine when, how often, and by what means the species should be studied. They also noted that most techniques for the measurement of populations have been developed for large geographic areas and large numbers of individuals, and that the estimation of populations for a small study area would require a local as well as a regional perspective.

It is recommended that these general guidelines be followed if indicator species are used to estimate changes in the quality of wildlife habitat at wetland treatment sites. The limiting factor or factors (habitat requirements) that determine the presence or absence of the species must be identified first. Appropriate species or groups of species are then selected. There may also be a threshold level for a particular factor below or above which the species will not use the habitat. This also should be identified, if possible. The threshold could be a particular water level, population of a species of food plant or animal, etc...

The presence and if possible the numbers (density) of indicator species should be measured in both treated and reference areas. These measurements should be made over the course of at least two and preferably three years in order to account for long-term variability.

2.8.9.4 Changes in Incidence of Disease, Wildlife Condition, and Potential Human Disease via Wildlife

The first steps to be taken in the design of a study of the effects of a wastewater discharge on wildlife health would include:

- Development of a matrix of parameters to be measured, organisms of concern, and optimal and problem conditions for each organism;
- Identification of potential organisms to be studied at each particular site; and
- Identification of disease organism-environmental parameter interaction studies to be done in the laboratory.

The studies to be conducted at a particular wetland should be coordinated with other research to avoid duplication of effort and to maximize the number of parameters and areas of concern that can be investigated. The following general outline of potential investigations on wildlife health at wetland treatment sites was developed by personnel of the USFWS National Wildlife Health Laboratory at Madison WI:

1. Direct measurements
    a. Diagnoses of causes of mortality

- b. Sampling of living populations
    - 1) Wild
    - 2) Sentinel - prior, during, after discharge. Test for impairment of biological systems using enzyme, hematological (blood), immunological, reproductive tests

2. Indirect measurements
    - a. Condition
    - b. Reproduction
    - c. Population dynamics (including lifespan)

3. Environmental quality
    - a. Microbial fauna - diversity, numbers; culturing at discharge
    - b. Water quality
    - c. Known disease problems
        - 1) Known areas
        - 2) Potential areas
        - 3) Control areas

Sentinel birds, mammals, reptiles, and amphibians could be used over periods of time to determine the potential for adverse effects on wildlife health. The sentinal animals used would have to be free from the diseases of interest. They would be maintained in the study area for various periods of time. Control sentinels should be placed on similar but unaffected reference areas for these experiments to be valid.

Hematological and chemical parameters also should be measured. The major factors to be measured are:

- Changes in health;
- Persistence and survival of organisms; and
- Comparisons between similar areas.

Nonlethal samples (such as from the trachea and cloaca of birds) could be taken from the sentinels for analysis. The samples should be sent to both the National Wildlife Health Laboratory at Madison WI and the Patuxent MD facility of USFWS (Patuxent Wildlife Research Center). The samples would be analyzed for both chemical and pathological contamination. State agency personnel or other researchers could maintain the sentinel wildlife, and collect and ship samples to the laboratories. Any bacteriological or virological fieldwork could be done by USFWS personnel from the Madison facility. For consistency, all such analyses from all study sites should be conducted by the same research facility, except for additional samples that may be sent to a similar facility as a quality control measure or to permit the use of more specialized equipment.

Because of the number of types of studies that could be performed, the complexity of the design and implementation of these studies, and the technical expertise and complex facilities required, it is recommended that appropriate personnel of the US Fish and Wildlife Service prepare the study designs for these investigations. USFWS personnel would be able to identify the timing and scope of each study element and the potential roles that state wildlife biologists and laboratory personnel or other researchers would play.

The studies would require long-term commitments of funds and personnel. The time frames, levels of effort, and products of such studies should be determined by USFWS in cooperation with USEPA and any other cooperating agencies or personnel involved (such as the Center for Disease Control Botulism Laboratory in Atlanta GA). Personnel at the USFWS Wildlife Disease Laboratory in Madison WI presently can perform research in the areas of parasitology, pathology, and virology, as well as some investigations on enzymes.

Several wetlands in Indiana have been identified by state agency personnel as receiving treated wastewater that contains flows from poultry production industries (the Maple Lane Duck Farm and Pokagon State Park). Live virus used for vaccination of poultry may survive the wastewater treatment process and enter a wetland treatment site, where it could infect waterfowl, pheasants, and other avian species that inhabit or visit the area. These or similar sites should be considered as candidate sites for studies of effects on wildlife health. The only site identified in the inventory of discharges as having experienced a botulism outbreak also is located in Indiana (Fremont IN).

2.9 METHODOLOGIES FOR INVESTIGATION OF THE POTENTIAL FOR ENHANCEMENT OF WILDLIFE HABITAT

The methodologies proposed for work in this area basically are the same as those proposed in Section 2.8.8: a review of the existing literature, holding a workshop, performance of field experiments, and the development of appropriate sections of a guidance document. Because of the close connection between these investigations, it is recommended that the components of both methodologies be conducted simultaneously by the same personnel. It is likely that the same literature sources would be used and that the same personnel would be contacted for study design assistance, worshop participation, etc...

The case study technique would be the most feasible method for development of examples of wetland restoration with the use of wastewater. Such studies should be performed on separate sites from those selected for case study investigations of primary and secondary impacts, however, because of the difference in objectives. The sites selected for the impact studies should be manipulated as little as possible to allow the identification of the responses of the various components of these systems to the introduction of wastewater. The sites for the enhancement studies should be considered as experimental laboratories for the testing of various techniques and combinations of techniques for habitat enhancement, in combination with control of the introduction, periodicity, and duration of wastewater flows. The sites used for primary and secondary impact studies could be used as control sites, and similar sites could be used as experimental sites at which various enhancement techniques are implemented. Data from both types of sites could be compared to obtain information on the effectiveness of the enhancement techniques at wetland treatment sites.

The designs and time frames for these experiments should be developed after the selection of the case study sites and the completion of the preliminary literature investigations. It would be preferable to do this after the workshop has been held, and to use potential case study sites as examples for use in the workshop. Information on several potential sites should be compiled and distributed to workshop attendees prior to the workshop. This material should be selected on the basis of the results of the initial site surveys and/or the information obtained during the inventory of sites prepared for this draft report.

The field research design should include before-and-after evaluations of control and experimental wetland treatment sites, both natural and artificial, to determine the changes in extent and quality of habitat. Some of these changes may not be possible to determine over the two-year field research period, but the methodology developed could be applied periodically by future investigators to determine longer-term habitat enhancement results. The fact that the surrounding upland areas provide habitat requirements for some species of wetland wildlife, in addition to the reverse situation for upland wildlife, must be considered in the selection of study sites and the development of study designs, so that the potential benefits to both wetland and upland wildlife are investigated. The effects of various adjacent land uses and management practices, such as grazing, mowing, and controlled burning, also must be taken into consideration in the investigation and analysis of the timing, intensity, and duration of wildlife use of a particular wetland.

An objective system for evaluation of habitat should be selected to be used in the measurement of habitat conditions and quality during baseline, operational, and monitoring phases at each of the sites selected for investigation. A number of non-monetary habitat evaluation systems were reviewed by Shamberger et al. (1979) and Harker et al. (1980). Although the Habitat Evaluation Procedures (HEP) developed by the US Fish and Wildlife Service constitute the most recent and objective tool for estimation of habitat value, their utility is greatest at present for large water resource projects rather than for the small wetlands that may be created or enhanced through the mechanism of wastewater application. The HEP procedures and valuation systems such as that proposed by Reppert et al. (1979) are relatively complicated and time-consuming to use, as compared to evaluation schemes such as that developed by the Michigan Department of Natural Resources (n.d.). The HEP and Reppert procedures are designed for estimation of the habitat value for representative, rare, and/or economically important species, depending on the criteria identified as important for the selection of the evaluation species for that particular site.

The applicability and cost-effectiveness of available evaluations systems to the needs of this study should be reviewed during the literature review and site selection tasks, prior to the design of the research program for this aspect of the full-scale study. If a simplified version of HEP is developed by USFWS personnel for use in Midwestern wetlands of various types, this method of evaluation could be used to determine the increase in habitat value from the enhancement/creation of wetlands by means of wastewater application. At present, other systems of evaluation appear to be more suitable.

All field research that involves the management of wildlife habitat and use of effects on fish and wildlife must be conducted in accordance with Federal and state policies and requirements. All necessary permits for research on government-owned or managed land, collection or use of migratory species, etc... should be obtained during the design phase of such studies.

The schedule for the implementation of these methodologies would be parallel to and coordinated with the methodologies proposed in Section 2.15. The field research should be correlated with the biological investigations proposed in Section 2.8. Because the timing of the tasks to be performed in both areas depends on a number of factors and decisions, no schedule for this work has been developed for this draft report. In general, the literature review and personnel contact tasks would begin during the early part of the Phase II study so that appropriate participants and information for the workshop could be developed as quickly as possible. Due to the time required for the site selection process and the workshop, it is possible that the field research tasks would not be performed until the second or third season of the first year of the full-scale study. On balance, it is likely that more valuable results would be obtained from shorter but well-designed studies than from studies that extend over a greater number of seasons but are not structured as well for the attainment of the desired results. The intent of these studies would be the testing of the feasibility and success of various alternatives, rather than the determination of the long-term effects of an environmental stress. Results could be obtained more quickly in this type of investigation because of the inclusion of the element of choice by individual wildlife in response to the situations created. Nevertheless, it would be preferable to conduct such studies over the longest time frame possible to allow for variability in weather conditions, discharge conditions or problems, types of wetlands, wildlife activity and habitat preferences, and other factors that may not be part of the experimental design.

The roles, activities, habitat requirements, and natural cycles of the various types of wildlife commonly associated with wetlands in the Midwest should be clearly understood before the research design is prepared. This is particularly true of animals such as muskrats and beaver, which play a major role in the creation and maintenance of water levels in wetlands. Muskrats in particular are opportunistic and can populate an area relatively quickly if conditions are favorable, increase in number to the point where disease becomes a limiting factor, and then be reduced to a relatively low level for an extended period of time. During this boom-and-burst cycle, they may "eat out" a wetland and alter its value for other species of wildlife significantly. Errington (1963, as cited in Weller 1978) has described the major characteristics of this cycle and its effect on avian populations. The research also must be correlated with the needs of other researchers at the sites and utilize the results of the other investigations where possible for minimization of time requirements and maximum cost-effectiveness. It is anticipated that the participation of Federal and state agency personnel will be required for the investigations proposed for this issue category.

2.10 METHODOLOGIES FOR INVESTIGATION OF EFFECTS ON HUMAN HEALTH

The major concerns identified by USEPA and by the participants at the scoping meeting for this project dealt with long-term and toxic effects of wastewater on the structure and function of wetland ecosystems. Methodologies for investigation of the potential effects on human health from the use of wetlands as treatment or discharge sites have not been developed in this planning study. Similar types of investigations currently being conducted for USEPA by other researchers include the following:

- Health risks from viruses in reclaimed waste waters - California Department of Health Services;
- Efficiency of water treatment methods on Giardia cyst viability - University of Oregon;
- Disease transmission associated with land application of wastewater - Hebrew University of Jerusalem; and
- Development of methods for detection of viruses in water and soil - Hebrew University of Jerusalem.

If investigations to determine the potential for an increase in the incidence of human communicable disease or the potential for alternative rates of transmission associated with wetland treatment/disposal are desired by USEPA, it is recommended that personnel at the schools of public health in Region V (University of Illinois, University of Michigan, and University of Minnesota) be contacted to participate in the development of such studies. If time and funds do not permit suitable field investigations, a survey of recent literature should be performed so that the results of recent research can be included in the study. Estimates of the potential for transmission of diseases to humans through consumption of fish and wildlife harvested from a treatment site or by means of biting insects can be made if the studies on insect, fish, and wildlife populations and associated disease potentials proposed in Section 2.8.8.4 are conducted.

2.11 METHODOLOGIES FOR INVESTIGATION OF EFFECTS ON PLANT HEALTH

Methodologies for the determination of changes in plant species composition, productivity, and distribution and uptake of toxic substances are discussed in Section 2.8. If desired, this research could be expanded to include collection of plants that appear to be diseased. The services of a plant pathologist would be required for examination of the specimens and identification of pathogens. A proper field sampling program should be developed if more detailed studies are desired, with selection of appropriate reference areas and sampling techniques.

2.12 METHODOLOGIES FOR INVESTIGATING EFFECTS ON ANIMAL HEALTH

The first organ of the body in which harmful functional changes occur is termed the "critical organ" or "target organ" (Duffus 1980). However, this organ may not be the one in which the greatest accumulation of the substance occurs. The critical organ is different for different substances and for acute and chronic exposure levels. For example, the lung is the critical organ for short-term exposure to high levels of atmospheric cadmium, but the kidney is the critical organ for long-term, low-level exposure (Duffus 1980). Changes that do not affect the function of the organ may provide an early indication of potential adverse effects. Measurements of the types and concentrations of blood constituents such as enzymes, serum proteins, and electrolytes can be used to determine the occurrence of changes in the function of various organs.

Because several toxic substances may be present simultaneously, it would be difficult to identify and to estimate the types and extent of effects due to each of the substances individually. Therefore, the health of animals in an area treated with wastewater should be compared with the health of animals in a similar untreated control area. This would require the use of "sentinel" fish and wildlife that are known to be uncontaminated and that can be maintained under controlled conditions. In order to adequately compare the effects of wastewater constituents on the sentinel animals in the treated area with the effects of the controlled conditions on the sentinel animals in the control area, the concentrations of the substances of concern must be monitored in the sediments, soil, water, invertebrates, and plants in both areas. These investigations will be performed during the water, sediment, and biological studies.

The ultimate goal of the research in this area is to identify the critical pathway for each toxic substance of interest through the ecosystem, so that indicator species can be identified and techniques developed for monitoring of key parameters or functions of these organisms for early indication of adverse effects. Duffus (1980) defined the critical path as the path from which the greatest harm may be anticipated. The organisms that constitute the first part of the path, such as certain macroinvertebrates, may be unaffected by the toxic substance themselves but may accumulate and possibly biomagnify the substance and then pass it on in concentrated form to higher levels of the food chain, including man.

The methodologies for the investigation of the effects of wastewater application on macroinvertebrates and insects are described in Section 2.8.6 Other than measurement of the effects on overall population and community health (such as species abundance and species diversity), no health effects will be investigated for these groups. Methodologies for estimation of effects on fish health are discussed in Section 2.8.7.4. Similar information for effects on wildlife health is presented in Section 2.8.8.4.

2.13 METHODOLOGIES FOR TESTING OF OVERLOADING AND STRESS

No methodologies are proposed for testing overloading here. However, effects of overloading can be roughly estimated by comparing impacts on wetlands which have received similar loads of wastewater discharges over varying periods of time. Some wetlands observed during the field survey appeared to be overloaded and these could also be studied. It is also possible that artificial wetlands could be used to study overload and stress effects simply by varying the areal extent of the receiving wetland. For example, a single discharge could be split several ways and routed through an equal number of artificial wetlands representing a range of sizes. This would be equivalent to varying the loading rate and would also allow the original discharge to meet the NPDES permit effluent limits for secondary treatment. The impacts on the receiving wetlands and the effectiveness of tertiary treatment as a function of loading rate could thus be determined.

2.14 METHODOLOGIES FOR INVESTIGATION OF DESIGN, OPERATION AND MAINTENANCE, AND MONITORING

2.14.1 Design

Hammer and Kadlec (1982) provide general guidelines for design of wetland wastewater application systems. The relative desirability of different types of wastewater application, application rates and degrees of required pretreatment of waters entering a wetland are poorly understood however. Some of these questions can be answered only by selection of sites suitable for such investigation. Discharges may be introduced to a wetland either as a point source or linearly via several points along a pipe. The majority of the sites identified during the inventory appear to be of the point discharge type, while current research projects at Drummond WI, Bellaire MI, and Houghton Lake MI are of the linear type. Thus, information is being developed that will prove useful for comparison of the relative merits of these two methods of application.

Additional design information will be provided by detailed studies on the three sites mentioned previously. The capacity of a given wetland to assimilate nutrients and to achieve other wastewater treatment goals will be identified as a result of the data collected. Size will undoubtedly be an important factor in the ability of a wetland system to deal with added wastewater. The sites chosen for investigation should therefore be selected partially on the basis of the volume of wastewater added per unit area of effective wetland. Because the type(s) and areal distribution of vegetation will be equally important, it will be necessary to examine sites that have different types of vegetative cover (i.e., cattail marshes vs. forested wetlands) in order to identify differences in water treatment capability.

2.14.2 Operation and Maintenance

Hammer and Kadlec (1982) provide guidelines for operation and maintenance of wetland wastewater application systems. A key variable with respect to operation is the periodicity of wastewater application. The majority of discharges probably are continuous during the period of application itself. Several study sites with different periodicities of discharges should be selected to permit interpretation and comparison of treatment effectiveness and impacts.

Common agricultural and upland spray irrigation practices, in contrast, utilize "resting" periods between periods of application of wastewater or fertilizer. This procedure leads to alternate periods of high and low oxygen content in the soil surface. Such periods may or may not be desirable for the optimal function of a wetland system for wastewater treatment. Some research has been conducted by USEPA which indicates that growth of certain wetland plants is much poorer under continued anaerobic conditions (constant flooding) (Sanville 1980). Gardner et al. (1972) in Lugo and Brown (1980) likewise found that water depth and associated soil conditions accounted for 94% and 85% of the variability in numbers of live and dead trees, respectively, in a sample plot. The number of stressed and dead trees increased with increasing water depth, and the number of live trees decreased. Tree survival following chronic flooding was shown to vary with tree size. Wetland plants grown in soil saturated only one-third of the time or those maintained in water saturated with oxygen grew more rapidly (Sanville 1980). It is recommended that this technique be investigated, however. Excess flooding has also been shown to increase the incidence of nonparasitic diseases (Filer 1972 in Lugo and Brown 1980) and to allow accumulation of toxic products and tranformation of oxidized metals to toxic soluble forms in soils (Lugo and Brown 1980).

2.14.3 Monitoring

Based on the results of the first year of the full-scale study and on additional, one or more experimental monitoring programs could be designed. The monitoring program(s) would incorporate elements of the research being performed that are identified as most effective in the determination of impacts. These programs could be tested at different types of treatment sites (both natural and artificial) within Region V for a period of several years. The parameters to be monitored could be tailored to the specific issues at each wetland.

2.15 METHODOLOGIES FOR INVESTIGATION OF ARTIFICIAL AND VOLUNTEER WETLANDS

2.15.1 Artificial Wetlands

Artificial wetlands exist at Listowel, Ontario (Wile et al. 1983), Humboldt, Sasketchewan (Laksman 1980), and Brookhaven, Long Island (Small 1977). Only the Listowel and Humboldt facilities currently are in operation. Other facilities are planned at Bement IL, Norwalk IA, and Wellsboro PA. Volunteer wetlands exist at a number of other locations, although these are not truly artificial because they were not designed as wetland treatment systems. No site preparation or vegetation establishment was attempted at those locations. Although information on the performance of artificial wetlands in wastewater renovation is not documented adequately at this time, the Listowel and Brookhaven experiences can be used as a basis for the qualitative interpretation of expected results and for planning of further investigations. The performance of volunteer wetlands similarly can be assessed to some extent, but the data base on these is not yet sufficient for design purposes.

The design and control of an artificial wetland treatment system would depend upon three key parameters: proper hydrologic control, proper soil substrate, and proper plant community establishment. Other types of vegetation would develop in some fashion, but would not be likely to influence the performance of the wetland in terms of wastewater renovation. However, the presence and diversity of these species and the diversity of habitat structure that they would provide would be important factors in habitat development and species preservation. None of the above factors, nor the harvest of biomass from such areas, have been researched to any extent. Appropriate diking and channelling would allow control of water levels and flow rates with relative ease. In summary, the major information needs at present are in the areas of substrate quantification and selection and establishment of wetland plant communities.

Based on the information presented above, it is proposed that investigations be made to determine both the transplant survival rate and the germination rate for seedlings and seeds of a number of species of commonly occurring wetland plants. These should include cattails, rushes, reeds, sedges, grasses (including wild rice), leatherleaf, willow, alder, and perhaps black spruce and tamarack. (Studies on the use of floating aquatic plants such as duckweed and submerged aquatic plants such as pondweed, both of which are fed on by waterfowl are more appropriately performed under laboratory conditions. These species are present for only part of the year, and populations vary with changes in a number of environmental factors.) It also would be possible to exercise some kind of control, and to obtain some research results, from the startup of facilities such as the artificial treatment system which was originally proposed (and subsequently dropped from consideration) as an alternative for Bement IL.

It is proposed to acquire a suitable site that is not currently a wetland, and to attempt to establish a variety of wastewater-tolerant species selected from the list above. Seedling survival and germination rate studies can be achieved within the time span of two years, and results are expected to be favorable, based on the work of Ewel (1979). Companion studies would involve the denitrification and phosphorus uptake rates expected from the soil substrates collected for the seedling and germination studies. Research currently has begun on some aspects of this type of work at Michigan State University (Burton, personal communication), and any research undertaken in this should be correlated with this ongoing work to avoid duplication of effort and to maximize the number and types of species to be examined.

2.15.2 Volunteer Wetlands

Any of the methodologies for research in natural wetlands described in any section of this report could be applied to the study of volunteer wetlands as well. Both site status surveys and in-depth studies should be performed at several sites.

Studies of such sites would yield valuable information on plant community establishment and vegetation productivity. Water quality information would be easy to obtain and transect information would be especially easy to obtain in these typically geometrical wetlands. Wildlife frequently make extensive use of such volunteer wetlands, and enjoy a protected status due to the access limitations. Volunteer wetlands also would provide convenient locations at which to conduct seedling germination studies. In addition, questions of harvest might be explored more easily in these situations because of the ease of vehicular travel. For example, the harvest of cattails could be accomplished by lowering water levels, allowing a sufficient period for drying of the vegetation, and then using common harvest techniques for collection of the above-ground biomass. Methods for the establishment and management of cattail are described in Weller (1975), Linde et al. (1976), and Beule (1979). Volunteer wetlands also would be well suited to studies that require the destruction of some component of the wetland ecosystem, because of the isolation of the sites and their present ownership.

2.16 METHODOLOGIES FOR INVESTIGATION OF MITIGATION TECHNIQUES

Time and funding restrictions during the present Phase I study did not permit extensive review of the many documents that contain information pertinent to mitigation of impacts on wetlands. It will be difficult to identify specific mitigative measures to alleviate the effects of wastewater on wetlands when these effects, particularly the long-term effects, are not yet known. It is anticipated that the results of the research to be performed during the Phase II study, when combined with research results from studies at other sites, would alleviate this information gap for some types of wetlands in USEPA Region V.

A second task that could be performed during this part of the full-scale study would be to hold a regional mitigation workshop to obtain input from various state and Federal agency personnel, university researchers, and other knowledgeable persons and to identify the mitigation methods most appropriate for use in the Region V states. This workshop also could serve to identify methods of habitat enhancement, including species and techniques suitable for restoration of wetlands and for creation of artificial or volunteer wetlands.

The results of the literature review and workshop could serve as the basis for the development of a manual for use by facility planners and operators, government personnel, and consultants. The manual could be a printed, full-size document with a bibliography, such as the one developed by USFWS to summarize impacts, levels of possible mitigative measures, and monitoring techniques associated with surface mining in the West (Moore and Mills 1977). It could be developed as a smaller, spiral-bound document suitable for field use, such as the one recently developed by USFWS for biologists assessing the impacts of coal-fired power plants (Lewis et al. 1978). If funds for such an effort would be limited, an inexpensive report-type manual without supplementary material could be prepared. An example is the wetland evaluation techniques manual being prepared by the Division of Land Resource Programs of the Michigan Department of Natural Resources (n.d.), which currently is in operational draft form.

Finally, it is recommended that an intensive, pre-operational baseline study be performed on at least one conventional wastewater treatment facility to be constructed in USEPA Region V during the next several years where the potential exists for impacts on wetlands. The area should be designated as a long-term study site, and the primary and secondary impacts should be monitored for a period of years, using a monitoring methodology such as that proposed by Marcus (1979). Because of the long-term research commitment, such a study most easily and efficiently would be conducted by state or university researchers. Similar studies should be done on at least one artificial wetland and one volunteer wetland.

The methodologies to be employed for the identification of appropriate mitigative measures are summarized in the following outline:

I. Conduct literature review and identify sources of information in Region V.

   A. Review known literature on mitigation to identify material appropriate to wetlands. Also review previous facility plans and EISs to determine types and levels of information currently used and needs for additional information. Examples of the types of mitigation measures to be investigated are included in Table 2.16-1.

   B. Conduct search of computerized data bases, abstracts, etc... for recent publications, ongoing research, or conferences.

   C. Request state agency contacts in Region V and personnel from appropriate Federal agencies, such as USFWS and US Department of Transportation (DOT), to determine if guidance documents or publications with relevant information are in preparation. Also request names of persons most knowledgeable concerning mitigation of impacts on types of wetlands in Region V and enhancement of habitat in such areas.

II. Conduct workshop (optional)

   A. After literature review task is completed, contact knowledgeable persons identified in previous task to obtain additional information, to develop structures for the workshop, and to request their ideas.

   B. Develop materials to be used at the workshop and select resource personnel to participate on the basis of the data gaps and needs identified.

   C. Hold 1 to 2 day workshop. Design personnel and regulatory personnel should be in attendance to explain types of facilities and needs of each group of users.

   D. Compile results of workshop and circulate to participants and appropriate reviewers for review and comment.

   E. Revise compilation if necessary.

Table 2.16-1. Examples of types of mitigation measures to be investigated.

Mitigation of Primary Impacts

- Purchase, development, or construction of replacement areas
- Careful siting of facility and interceptors
- Control of sources of impacts (avoid fill, control erosion and sedimentation, revegetate quickly with natural cover, etc.)
- Design and proper operation of ponds to avoid botulism problems
- Timing of construction to avoid disruption of animal reproduction periods
- Proper management
    - Timing of harvest (if managed artificial or natural wetland) to avoid flooding of cut plants such as cattail, which survive only one year after flooding (Weller 1975)
    - Maintain optimum open-water vegetation ratio for wildlife (Weller 1975; more enhancement than mitigation)
    - Maintain appropriate loading ratio
    - Timing and duration of discharge and control of discharge rate to coincide with natural hydrological cycle (may require design of larger retention ponds)

Mitigation of Secondary Impacts

- Selection of facility plan alternative that is likely to result in least amount of induced growth in or near wetlands in the planning region
- Restriction of usage of site and adjacent buffer areas by various physical means (fencing, posting)
- Restriction of impacts on other wetland areas by development of regulatory means (state or local ordinances, land-use plans, legislation)

Mitigation of Impacts of Research Investigations

- Construction of elevated walkways
- Determination of minimum quadrat size and number of replicates needed for biomass samples, water quality monitoring stations, trap lines and sampling transects, etc. - conduct stratified random sampling
- Use nondestructive sampling methods where possible

III. Develop guidance documents

A. Based on the information obtained from the literature review, the workshop, and the results of the field investigations from the full-scale study and from similar investigations, identify the potential impacts and mitigative techniques. Also note the other factors likely to be present that would exacerbate these impacts and increase the overall stress on the wetland ecosystem or on particular components of the ecosystem.

B. Arrange information in logical sequence by phase (construction, operation, or monitoring), by type of facility or treatment system, and by type of impact. Use cross-referencing or indexing systems as necessary. Develop illustrations and tables, matrices, and flow charts to present information in simplified, easily usable manner

1. Include information on use of habitat evaluation methods as appropriate to types of wetlands or levels of mitigation activities required.
2. Explain mitigation policies of agencies involved, including FWCA requirements (check for updating or additions).
3. Include information on resource personnel in each state and USEPA Region V available for consultation.
4. Include overview of major problems and appropriate corrective actions.
5. Include mitigation of impacts from recreational, educational, or research uses of site.
6. Include guidelines for methods of enhancing wetland habitats, and resource personnel to contact in each state.

C. Prepare text and layout for various mitigation guidance documents as required. Develop appropriate section for each document on how to use document.

1. Manual for designers and planners
2. Guidance documents for impact assessment and review

D. Submit draft products to USEPA and to knowledgeable technical personnel (designers, biologists, review personnel) for examination and review

E. Revise and print or submit to USEPA for publication.

2.17 METHODOLOGIES FOR INVESTIGATION OF LEGAL, ADMINISTRATIVE, AND REGULATORY CONSIDERATIONS

Because of the lack of information in this area of investigation, a number of methods could be used for compilation of legal and regulatory information. However, because of the early status of the technology of using natural or artificial wetlands as treatment sites and the consequent lack of regulations and policies in this area, the participation of personnel at a number of levels in federal, state, and local government would be required for the effective performance of the studies proposed in the following sections. The participation of these personnel should be coordinated by a neutral, non-governmental party to ensure that all viewpoints and concerns are given equal consideration. It is recommended that the report be based on and/or modeled after previous work by researchers in this area, and that personnel from an organization such as the Environmental Law Institute be involved in the design and conduct of the study, either in an advisory or a participatory capacity.

The areas of investigation, based on the issues and concerns identified in Table 2.2-1 of the main Phase I report include:

- Identification of the present federal and state policies, laws, and regulations applicable to the use of natural, artificial, and volunteer wetlands as wastewater treatment sites;
- Identification of the potential conflicts in jurisdictions between various levels of government and between different states in USEPA Region V, assessment of the implications of these conflicts for the development of alternative technologies involving wetlands, and identification of potential measures to facilitate interagency cooperation and to reduce or eliminate these conflicts;
- Determination of the consistency of the use of natural wetlands for wastewater treatment or discharge with current and pending wetland protection laws and regulations;
- Identification of the potential legal problems involved with the use of wetlands as treatment sites;
- Identification of the potential funding sources and responsibilities for the acquisition, monitoring, and possible maintenance of a wetland treatment site for wildlife habitat or as a natural area in addition to its use as a treatment site;

- Identification of scientific and management information required for the development of site selection, design, and monitoring criteria for wetland discharge or treatment sites; and
- Investigation of the public opinion of the use of natural wetlands for wastewater discharge and treatment and a comparison of these results with similar estimates of the acceptability of the development of artificial or volunteer wetlands for such purposes.

2.17.1 Present Policies, Regulations, and Laws

A literature search should be performed to identify the present status and content of Federal, state, and local laws and regulations applicable to wetland discharge or treatment sites. Because of the multitude and variety of such guidelines at the local level, one or more communities in each state in Region V that have wetland protection ordinances or other pertinent ordinances should be selected as examples. This task could be done primarily through mail and telephone contact with designated agency contact personnel who would be responsible for collection of the appropriate materials for a designated agency. A coordination conference could be held after the draft report for this task was prepared and circulated for review and comment. The participating agencies, in addition to USEPA, may include other Federal agencies with jurisdiction in the Region V states, the six state pollution control agencies, and other state agencies with appropriate responsibilities related to wetlands. Representatives of public and other groups could attend as observers, if feasible.

Additional information may become available during the course of the Phase II study, such as a handbook on existing state and local government regulatory programs that will include programs that control activities on areas adjacent to inland wetlands (Environmental Law Institute 1980). This document will be prepared jointly by the staff of the National Wetlands Newsletter and personnel from the Maryland Coastal Zone Management Program, and is expected to focus on mitigation measures.

2.17.2 Identification of Conflicts

The report described in Section 2.16.1 also should include:

- Identification of present and potential conflicts and identification of mechanisms to facilitate interagency cooperation and to eliminate conflicts in jurisdiction, requirements, etc...; and
- Identification of the compatability of the use of natural wetlands as wastewater discharge or treatment sites with existing wetland protection regulations, policies, ordinances, etc...

Although the identification of apparent or potential conflicts may be made by the personnel who conduct the literature review, the actual determination of the consistency of wetland treatment technology with a particular law, regulation, order, or policy must be made by appropriate personnel from the sponsoring agency during the comment period for the draft report.

2.17.3 Legal Problems

The identification of potential legal problems associated with the acquisition, use, and change in use of a wetland used for wastewater treatment, and possibly adjacent buffer areas also should be performed by personnel trained in legal procedures and actions. The "taking" issue in particular has been of concern in many court cases dealing with wetlands regulations and use (Kusler 1980), and undoubtedly will be a major issue at some proposed wetland treatment sites. This task can be initiated prior to or concurrent with the investigations indicated in the previous sections, but will depend on the information collected in these tasks and thus should be closely correlated with them or performed by the same personnel.

2.17.4 Potential Funding Sources

This effort can be performed by the researchers for the previous four tasks if sufficient information is provided by the agency contact persons or by others who are familiar with current and proposed funding programs at both Federal and state levels. It also may be appropriate for this to be a joint effort during the coordination conference or a workshop attended by the researchers and the contact persons.

2.17.5 Identification of Scientific and Management Information

This task should involve the principal researchers for the legal regulatory work, the principal investigators for the field research studies, state and Federal agency personnel, and other appropriate persons as identified by USEPA or other agencies of concern. If possible, a meeting should be held just after the completion of the literature review tasks by the various field research investigators. If this is not possible for financial or other reasons, a conference or workshop could be held at the end of the first year of field research, when the preliminary results of the field studies Based on these results, and the results of studies at other treatment sites under investigation, additional parameters may be included for investigation or current research designs adjusted to provide the desired information. However, it is recommended that such determinations be made prior to the initiation of the first year of field investigation, to permit the collection of several years of comparable information using the same research designs and sampling techniques.

2.17.6 Community Acceptance

A survey of community or governmental acceptance could be performed through interviews with landowners or key personnel in the decision-making process. The survey form developed by Dworkin (1978) could be adapted for use in the investigation of community acceptance of wetland treatment sites. The results of her study also would be helpful in the development of public participation programs on the use of natural or artificial wetland as a wastewater treatment alternative. If time and funds permit, a similar or less extensive study could be performed at one or more communities in USEPA Region V where a wetland treatment alternative is proposed. Although such a study may overlap the time frame for the field research elements of the Phase II study, its results would prove useful to USEPA and other agencies for other situations, and possibly could be incorporated into an EIS if such a document is prepared. If possible, the study should include a comparison of opinions for sites at which artificial or volunteer wetland alternatives also are considered, or several different case study sites at which each of these alternatives is related to conventional technical treatment.

2.17.7 Case Studies

It is proposed that the history of the regulatory process for and subsequent development of one or more wetland discharge sites be followed and recorded during the course of the Phase II study. This documentation could be combined with or conducted in parallel to the study on community acceptance of wetland treatment sites proposed in Section 2.16.6. The effectiveness of the various techniques, policies, and regulations developed and the problems encountered at each stage in the process would provide valuable information for initiators, planners, and regulators of other such projects. The potential legal problems in particular may vary with different states, local jurisdictions, communities, types of wetlands, and wetland uses, and types of wetland treatment systems (location, design, use of natural versus artificial wetland, etc.).

2.17.8 Final Report

A final report of the results of the investigations and the conferences or workshops described in this issue category should be prepared for use by USEPA and other governmental agencies in Region V. This document may be published as a single entry, if desired, and/or its contents summarized or tabularized for inclusion in a generic EIS on the environmental effects and issues associated with wastewater treatment facilities adjacent to or involving wetlands.

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APPENDIX B

PRACTICAL CONSIDERATIONS FOR PLANNING WETLAND TREATMENT FACILITIES

Practical Considerations for Planning Wetland Treatment Facilities

The purpose of this Technical Report and the future EIS is not to be a design manual, although EPA is developing other publications in that area (Hammer and and Kadlec, 1982). There are some practical thoughts and precautions for those considering a wetland alternative, which have arisen from developing this technical report.

The success of employing natural processes in a wetland treatment system for wastewater largely depends on the site's characteristics and both the planner's and designer's understanding of the specific system on hand. There is a great diversity both between wetland types and among individual wetlands of the same general type. They differ not only in the kinds of vegetation present but in their hydrology, productivity, nutrient cycling, soil adsorption capacity and other characteristics. This natural variability makes a static engineering approach unwise and certainly less workable then with conventional modes of wastewater treatment.

Because of the site-specific differences of wetlands, it is critical to understand the nature of the site at the project planning stage rather than to adopt a standardized design approach. Robert Kadlec (personal communication, 1983) has developed an informal, 2-step outline for evaluating potential sites in the planning phase:

I. Site Identification and Preliminary Evaluation

  A. Goals

    1. Determine the size, type and location of potential wetland sites.

    2. Determine wastewater parameters, and treatment requirements (of State Water Pollution Control Agency).

    3. Estimate hydrological and water quality status of potential sites.

    4. Determine ownership and current management of sites.

  B. Tasks

    1. Inspection of USGS maps, aerial photos.

    2. Ground level visual inspection.

    3. Collection of existing data on hydrology and water quality, for treatment plant and wetland.

    4. Estimate organic matter depth and type.

    5. Determine all links in the network of ownership and management.

II. Final Site Feasibility Determination/Preliminary Design

  A. Goals

    1. Hydrological patterns

2. Water quality
3. Organic matter type and depth
4. Nutrient status of water, organic matter and flora
5. Types and relative abundance of algae
6. Cover types and geographical distribution
7. Treatment potential
8. Vertebrate use patterns
9. Human use patterns

B. Tasks

1. Water budget
    a) Annual precipitation, cloud cover and solar radiation data acquisition.
    b) Streamflow data.
    c) Water level records for wetland and adjacent water bodies.
    d) Subsurface flow patterns.
    e) Surface elevation survey.
    f) Overland flow patterns.
2. Water quality
    a) Nitrogen, phosphorus, chloride.
    b) Coliforms, BOD, suspended solids.
    c) pH, temperature, conductivity.
3. Soil processes
    a) Type of organic matter
    b) Ion exchange capacity of soil
    c) Permeability
4. Flora
    a) Algae inventory.
    b) Plants - cover map, identify threatened and endangered species, State and Federal.

5. Use patterns.
   - a) Vertebrates (muskrats, beaver, ducks, geese).
   - b) Human.
6. Treatment potential small scale testing
   - a) Small, brief irrigation test. (Tank truck and pump, ca. 1000 gpd for 20 days).
   - b) Assess nitrogen, phosphorus removals.
   - c) Assess water depth and movement patterns at discharge site.
   - d) Assess suspended solids, BOD removal.
   - e) Check plant, soil and algae response.
   - f) Estimate full-scale treatment parameters.
7. Develop environmental assessment report.

Implementing a potential wetland treatment system involves political as well as technical factors. The planning stage is the ideal time to begin informal discussion with the State and Federal regulatory agencies responsible for water pollution control, fish and wildlife resources and wetlands. Regulatory requirements can be clarified and mitigative measures can be considered. Recognize that for regulators there are frequently questions and controversy between the value of the effluent as a resource and the capacity of wetlands to accomplish wastewater treatment. Philosophical differences may also exist between the wastewater and the wetland management objectives at a site. At present, many technical questions are unresolved, as this report demonstrates. It is important for all parties to take the time and patience to arrive at some common ground in these planning discussions and to consider potential mitigative measures. EPA Region V is working to develop informal procedures in this area.

Using natural wetlands for wastewater treatment is likely to be more controversial than constructing "artificial" wetlands. Some situations where application to wetlands is clearly unwarrented include rare or fragile wetland types, such as a fen, or to a recognized wetland preserve or special resource area. Other situations are much more amenable for consideration, such as a small community located by large expanses of wetlands, with few large streams in the area. Constructed wetlands present their own special considerations and planning needs. Flow patterns and transit time need to be carefully planned. Mechanical harvest is indicated for nutrient removal and maintenance of hydraulic capacity.

With any wastewater technology there are trade-offs of costs, environmental impacts, environmental benefits and implementability. For innovative or alternative technologies it is important to analyze these trade-offs against the risks of conventional treatment processes rather than a hypothetical "zero risk" situation. For example, waterfowl impacts from treated wetland interaction could be compared to actual waterfowl use of conventional sewage treatment lagoons. Neither situation is ideal, but they are comparable alternatives.

As with other types of alternative technology, good planning is the key to selecting a alternative when examining the option of wastewater application to wetlands. Sufficient time and resources must be devoted to understanding the site-specific alternative(s) and to evaluating whether or not they are workable, desirable and cost-effective.

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